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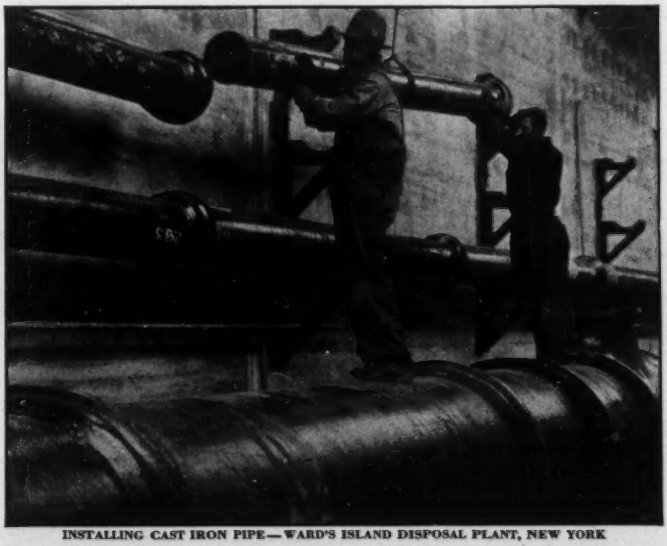

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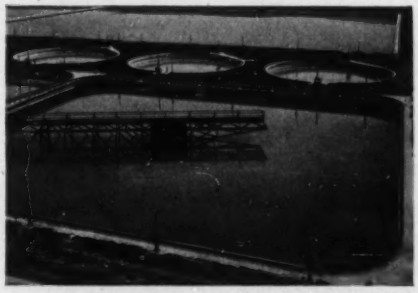

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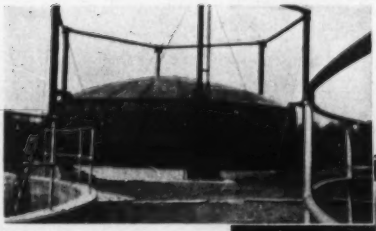

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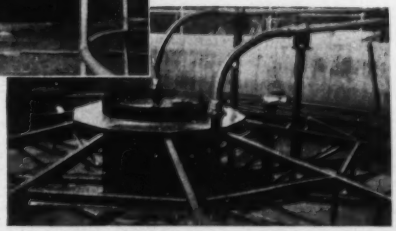

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Sewage Research

Sludge Disposal and Future Trends*

By Willem Rudolfs and E. J. Cleary

Chief, Dept. Sewage Research and Graduate Student, Rutgers University, New Brunswick, N. J.

The success and efficiency of a sewage treatment plant may be in large part measured in terms of its ability to provide for ultimate disposal of its most important by-product, sludge. The weight of dry solids removed in one way or another from the sewage is but a fraction of the weight of liquid sludge, but large proportions of these solids are highly putrescible and, except in the case of well digested sludge, are still capable of rapid decomposition. It is a problem of no small magnitude to rid the plant economically, and without creating offense, of its treated and untreated sludge. It is the purpose of this paper to review the various methods of sludge disposal and indicate the possible and probable direction of development.

In Large Bodies of Water.—Large bodies of water offer an easy means for the complete and final disposal of sewage sludge. Some communities make use of streams during flood conditions for discharging sludge and although this is usually not approved by State Boards of Health, there are instances where no harm is done, especially where the streams are large. As a general practice this method is condemned as unfair to the inhabitants along the stream below the point of discharge. In Great Britain many of the seacoast towns barge their undigested sludge to sea, while in the United States this method is used at the Passaic Valley, Providence, New Haven and other plants, and it is at present proposed for the new Wards Island plant in New York. Digested sludge from Imhoff tanks has been discharged into Lake Erie for some years at the Westerly Plant in Cleveland.

Lagooning.—Lagooning of sludge at one time was used more widely than any other means of disposal. However, at the present time it has been displaced to a large extent in this country. It is still practised abroad, especially if the settled sludge contains considerable quantities of inert trade wastes. Sludge is lagooned either digested or undigested and requires comparatively large areas. Odor, fly and mosquito nuisances often attend this method of disposal.

* *Journal Series Paper, N. J. Agricultural Experiment Station, New Brunswick, N. J. Dept. Sewage Research.*

The presence of industrial wastes is sometimes of advantage, as at Syracuse, N. Y., where sludge is removed continuously from the sedimentation basins and pumped two miles to lagoons, where it is mixed with many times its volume of industrial wastes from the Solvay chemical works. The sterilized effluent discharges from the lagoons into Lake Onondaga. At other places the sludge production is so large and of such a nature that digestion is either slow or difficult and it has been found expedient to make use of lagoons as an auxiliary measure. Large quantities of sludge from the Imhoff tanks at Akron, Ohio, necessitated the construction of lagoons with a capacity of 200,000 cubic yards. At the same time it was found that the humus from the secondary tanks gave considerable trouble when introduced into the digestion compartments of the Imhoff tanks. The most practical solution for this problem was disposal of the humus sludge into lagoons. Delivery of activated sludge to suitable low land is also practised at Houston, Texas. Digested sludge is lagooned at Ft. Worth, Texas. Generally, lagooning gives satisfaction where large parcels of land are available and there is limited rainfall.

Irrigation and Trenching.—Other methods of disposal on land, aside from the lagooning process, include irrigation and trenching. The former procedure has been used at a number of small plants in this country adjacent to farm lands and it has been entirely successful at the large plant at Canton, Ohio.[10] At many plants in England wet sludge is distributed over the land and as soon as possible thoroughly incorporated with the surface soil. Generally, it is necessary to prepare the land by plowing or digging furrows, although at some places the sludge may be applied by flooding. It has been found that the addition of milk of lime to the sludge assists in the separation of water and tends to prevent odors. About twenty cities in the semi-arid section of Texas employ broad irrigation for the disposal of sewage, which suggested the adoption of this method in handling excess activated sludge at the San Marcos plant, serving a population of 6000 people with an average flow of 0.35 m. g. d. Eggert and Cohen[5] claim that although the plant is located near the center of town there is no odor nuisance and no trouble of any kind has arisen from this method of sludge disposal. The city of Rochester in the course of investigations with sludge as fertilizer suggested that liquid sludge might be hauled away from the plant and sprayed on farm lands or golf courses. In Bedford, England, investigations along similar lines indicated that 86 per cent more fertilizing value had been found in liquid sludge than in the dry form.

Trenching has found little or no favor in this country, but at Wakefield, England, sludge has been disposed of in this manner for twenty years. The population served is more than 47,000 and the daily dry weather flow 2,500,000 gallons. The Irwin Creek plant at Charlotte, N. C., has

disposed of its undigested filter cake sludge in trenches upon tillable land, requiring approximately twenty-five acres of land per million gallons of sewage treated per day. McConnell[18] states "this procedure is an unsatisfactory solution to a vexing problem, and the whole scheme is dependent on weather conditions." Similar results have been found elsewhere.

Drying Beds.—The object of drying sludge is to reduce the moisture content to such a degree that the sludge can be easily handled for further disposal as fertilizer or fill for low land. Common practice is to run the wet sludge on specially prepared sand beds where part of the water percolates through the sand into underdrains and part evaporates. The character of the sludge has much to do with its behavior on the drying bed and it should be appreciated that no two sludges are the same in their consistency, moisture content and drainability. Generally speaking, sludge with a moisture content between 60 and 70 per cent may be considered as a satisfactorily dried cake. In the case of activated sludge, the process of drying on a sand bed is a slow one, particularly when it is applied in depths over five inches, since the rapidly settling suspended matter tends to clog the pores of the sand before the water can pass through and a large part of the water can escape only by evaporation. Undigested trickling filter sludge has similar characteristics. The material from chemical precipitation tanks when spread on drying beds will lose only a small portion of its moisture even after several weeks of drying and a slimy sludge, the consistency of lard, remains. Sludge from plain sedimentation basin and single story septic tanks in most cases possesses a very offensive odor and although it may be dried on sand beds the nuisance created is very objectionable. The well-digested contents from digestion tanks contain a large quantity of gas which carries the solids to the surface when the sludge is first placed on the drying beds and the comparatively clear water on the bottom quickly percolates through the bed leaving the solids to sink down slowly to form a spongy mat.

Drainage and Evaporation.—The functioning of a sludge drying bed is dependent on drainage and evaporation. Drainage is controlled by the physical construction of the bed and by the character of the sludge, while evaporation is correlated with climatological factors of temperature and rainfall. Rudolfs and Lacy[21] made an investigation of the relation between drainage and evaporation in sludge drying, stating that before any improvements in this process could be made more information was needed to establish the relative importance of these factors. They classified the moisture in sludge as (1) free water, which fills the interstices between individual particles, most of which can be removed by gravity filtration; (2) capillary water, which requires a force greater than gravity to free it from the capillary spaces of individual particles, a portion of this water

being removed by evaporation at the temperatures employed; (3) combined water, which can neither be drained off nor readily removed by evaporation at the comparatively low temperatures used. Of the total amount of moisture in sludge only 5 per cent is combined water, whereas capillary water amounts to approximately 42 per cent and free water constitutes the remaining 53 per cent. At the low temperatures generally employed, evaporation does not play a major role until all the free water is drained away, but at higher temperatures evaporation is effective from the very beginning of the drying period.

Conditioning.—Chemical treatment of digested sludge with aluminum sulphate, ferric chloride, copper sulphate, etc., has been found very effective as an aid to rapid drying on sand beds. The quantities of chemicals required vary with the type and degree of digestion of the sludge. At Plainfield the addition of 3 lb. of alum per cu. yd. of sludge cuts the drying time in half. Alum conditioning of undigested activated sludge, involving 5 to 7 lb. of aluminum sulphate per 1000 gallons, is used at Tenafly, N. J.,[4] in conjunction with drying under glass-covered beds.

Open Drying Beds.—Sludge drying beds are usually constructed in widths of 20 feet, this dimension being convenient in connection with the loading of the dried cake by hand on dump cars. Lengths between 50 and 100 feet insure satisfactory distribution of sludge from one inlet. The bed is generally surrounded by a concrete curbing of earth embankment high enough to hold a maximum charge of 12 inches of sludge. The drying area required varies with: (1) The strength of the sewage treated; (2) The character of the sludge produced (moisture, volatile matter); (3) Climatological conditions.

From 0.33 to 3 sq. ft. per capita is provided at different places for digested sludge.[25] Much higher allowances should be made for other types of sludge, ranging as high as 7 sq. ft. per capita for activated sludge and sludge from chemical precipitation tanks. In semi-arid climates or with glass-covered beds reductions in required area up to 50 per cent are permitted.

The optimum depth to apply wet sludge must be determined at each plant. A study of data from a great many plants reveals that the depth may vary from 8 to 12 inches. "It is obvious that the less the depth of wet sludge the more quickly will it dry. However, it is equally obvious that if sludge be applied too shallow, the available drying area will be used up without getting rid of very much sludge. Furthermore, practically just as much sand will be taken away with a thin cake as with one somewhat thicker, and the man-hours required to remove a thin cake are almost as high as for the removal of a thick cake."[3] The number of doses given each year to a bed is dependent on local conditions. At

Plainfield over a period of five years the average number of dryings per year has not amounted to more than seven; at Fitchburg, Massachusetts, only five or six doses per year can be applied. These results indicate, respectively, the possibility of drying 0.22 and 0.176 cubic yard of wet sludge per year per square foot of drying area. At Baltimore the open drying beds cover a total area of thirteen acres, thus providing 0.67 square foot per capita.

Perhaps the most modern mechanical method for cleaning sludge beds has been developed by the Sanitary District of Chicago. At the Calumet Treatment Works a machine is installed[7] to clean six drying beds, each 105 feet by 65 feet in size. The machine consists of a series of specially shaped buckets working on an endless vertical chain quite similar to a ditch digging machine. The buckets dig into the sludge at a speed of 20 feet per minute and the elevator raises the sludge to a point where it is dumped on conveyors and carried to the edge of the bed into narrow-gauge dump cars. The buckets can be elevated or lowered to strike the exact sand level; on a bed with five inches of dried cake they pick up about 1.25 cubic yards per minute. Two larger machines of different types have been installed at the West Side Treatment Works, working on beds 80 by 1200 to 1500 feet long, with a total area of 27 acres.

Glass-Covered Beds.—Greenhouse structures have been used to cover sludge drying beds in an effort to reduce the area of beds required by protecting the drying sludge from unfavorable weather conditions. Many other advantages have been stated, among which are the control of odors, adaptability to landscaping programs, reduced sludge drying area requirements, and possibility of accelerated drying through controlled ventilation or the use of hot air. Although glass-covered beds might be considered as new developments we have record of a small institutional plant near Pleasantville, N. Y., making an attempt in 1915 to control odors originating in a sludge bed by covering that bed with horizontal glass frames similar to those used in hot-bed construction.[2] There are probably older attempts which have escaped our attention. The present day development is embodied in the sludge-bed housing at Dayton, Ohio, the largest installation to date, where 105,000 sq. ft. of glass-covered beds are in use. The cost of building class-covered sludge beds varies appreciably but appears to lie between $2.50 and $3.00 per sq. ft., of which, roughly, two-thirds may be regarded as the price of the covering. However, with a glass-covered bed it is usually permitted to use a 50 per cent reduction in required area so that in reality for the same sludge drying capacity glass-covered units are only 33 per cent higher in cost than the open beds.[3]

Glass-covered beds assimilate the heat from the sun, thus accelerating evaporation, provided good ventilation is maintained. Laboon,[17] in

1930, made extensive observations on air currents in covered beds, using smoke candles burning outside the enclosures with different combinations of open and closed windows. He concluded that for best results the enclosures should have sidewall sash hinged at the top to swing inward and with the glass side walls located as close to the sludge line as possible. If ridge sash must be placed high above the sludge line, improved ventilation is possible with blower fans and air ducts located near the sludge line.

After sludge has dried sufficiently to become spadable it may be removed from the beds either by hand or mechanical methods (overhead monorail or a narrow-gauge industrial track system with hand forking into cars).

At Marion, Ohio,[3] ten covered sludge beds were operated at maximum capacity and in one year a total of 20 dosing and cleanings were made. The period of drying varied between a minimum of 6 days and a maximum of 43, thus averaging 16 days. Moisture content of applied sludge averaged 92.9 per cent and the dried cake averaged 67.5 per cent. The glass-covered beds at Tenafly, N. J., yield approximately 35 pounds of dry solids per square foot per year. It has been reported[4] that the addition of one to two pounds of copper sulphate per thousand gallons of sludge assists materially in controlling the odors from the undigested activated sludge at Tenafly.

Filtration.—The process of filtering sludge through cloth is dependent on a number of factors, physical and chemical, modification of which is brought about by the addition of a conditioning agent such as sulphuric acid, lime, alum, chlorinated copperas, ferric chloride, paper pulp, diatomaceous earth, etc. These conditioners eliminate to a great degree the undesirable properties retarding the dewatering process. Their application, particularly in the disposal of activated sludge, has been investigated by Mohlman, Palmer, Wilson and a number of others. Temperature, hydrogen-ion concentration and rate of coagulation were found to be important factors in the rapid filtration of activated sludge through cloth. Wilson[29] stated that at 45° F. the time required to dewater a given quantity of sludge was twenty times greater than that required for the same sludge at 70° F. The adjustment of pH (changing the negatively charged sludge particles) inhibited the tendency of the colloids to break up into smaller particles, thus inducing coagulation to take place. Sulphuric acid and alum[28] with its positively charged colloidal alumina were used to accomplish coagulation until Mohlman and Palmer[30] pointed out that iron salts, particularly ferric chloride, were far superior to alum. The then high cost of ferric chloride led to successful investigations with the use of chlorinated copperas (ferrous sulphate), a mixture of 71 per cent ferric sulphate and 29 per cent anhydrous ferric chloride. The cost of

ferric chloride was later reduced to such a degree that it was found to be preferable to chlorinated copperas for sludge conditioning. Further experimental work showed that the addition of fresh solids to activated sludge permitted higher rates of filtration and a smaller amount of chemicals for coagulation. At Chicago, rates of filtration using mixed sludge ranged from 2 to 9 lb. per sq. ft. per hour, whereas at Milwaukee and Pasadena activated sludge alone can be filtered at a rate of only 1 to 2 lb. per sq. ft. per hr.[19] Digested sludge at Baltimore and Columbus filtered at rates of from 3 to 20 lb. per sq. ft. per hour.

Filtering Devices.—There are three general types of filtering devices, all of which utilize changes in pressure to accelerate filtration. Many other attempts have been made to filter sludge by means of gravity, through fine wire mesh, filtros plates and absorbent material, such as garbage and tankage, all of them largely unsuccessful. We may classify the effective methods as:

(1) Chamber or leaf filter presses in which the sludge is put under pressure.
(2) Bag presses, in which bags containing the sludge are squeezed.
(3) Vacuum filters, in which sludge is dewatered by suction.

The plate-and-frame or recessed-plate filter press has been widely employed in the chemical industries.

The bag presses are mechanical devices arranged to apply hydraulic pressure to a series of bags filled with sludge. The Worthington Press had bags filled at the top suspended between built-up drainage sheets and squeezed by large platens worked by a toggled joint. The Berrigan Press has bags filled from the center, suspended between drainage sheets of hard wood slats and squeezed by direct pressure on the heads of the press. At Chicago both of these types have been investigated.

The Oliver type vacuum filter is used as a mechanical means for dewatering activated sludge at many of the larger treatment plants in this country. It is a continuous filtering mechanism consisting of a drum divided into sections and covered with filter cloth.

At Pasadena the sludge from the dosing tanks is dewatered in three Oliver filters, 11 ft. 6 in. in diameter and 14 ft. long, revolved very slowly by 5 h.p. motors. These filters are covered with heavy wool cloth held on by wire bands. The drum is submerged in a depth of 3 feet of sludge and a vacuum of 21 to 25 inches is applied. The cake which forms on the outside of the cloth is scraped off by a thin plate, aided by internal air pressure. The cake, dark in color and with the texture of blotting paper, is passed along on a conveyor over which is suspended a series of sharp-edged disks, which cut the cake into small pieces before it enters a heat drier.

Twenty-four Oliver continuous filters of the same size as those at Pasadena, each with an effective filtering area of 495 sq. ft., dewater the Milwaukee activated sludge from 99 per cent to about 82 per cent moisture content.

Chicago has operated a 11 ft. 6 in. diameter by 16 ft. face Oliver filter with an area of 570 sq. ft., installed as a pilot installation at the West Side Sewage Treatment Works, on a mixture of raw settled solids and activated sludge. The sludge was dosed with from 4 to 6 per cent anhydrous ferric chloride, based on dry solids in the filter feed, and the filter cake containing approximately 80 per cent water. Filter cake was produced at rates of 3 to 6 pounds of dry sludge per square foot per hour More recently Imhoff sludge has been filtered. At Baltimore an experimental unit has been operated on digested and semi-digested sludge. Ferric chloride was used, ranging from 5 to 14 per cent anhydrous material on a dry solids basis; filter rates averaged from 6 to 15 pounds of dry solids per sq. ft. of filter area per hour, with a cake moisture of from 73 to 75 per cent. Similar investigations at Columbus[12] with Imhoff sludge, using ferric chloride as a coagulant, produced a cake from the 3 ft. diameter by 2 ft. face Oliver filter at the rate of 4 to 5 pounds of dry solids per sq. ft. per hour, with a moisture content between 70 to 72 per cent. Other experiments have been made at Salem, Ohio, Charlotte, N. C., Winston-Salem, N. C., and several other places.

Keefer and Cromwell[14] in their vacuum filtration investigations at Baltimore, using a filter of the Genter type, concluded that the capacity of the filter depended on the speed of the filter, which in turn was dependent on the quantity of coagulant used, and that both the Genter and Oliver type filters were suitable for vacuum dewatering.

Constant efforts are being made to handle sewage in a more economical manner and one of the newer developments is the use of ground paper pulp with vacuum filters. At Dearborn, Mich., a plant was designed and built for the treatment of 8 m. g. d. of sewage based on experimental work using a mixed coagulant consisting of lime, ferric chloride and paper pulp in conjunction with vacuum filtration.

Many advantages are claimed for vacuum filtration, particularly in the disposal of activated sludge and as an intermediate stage between treatment and incineration or fertilizer manufacture. Aside from these considerations filtration is a continuous operation, obviating the storage of sludge over long periods, especially in the winter time. The process requires less space than other drying methods and it can be carried on in a building, independent of weather conditions and with opportunity for odor control. Keefer[14] states that at Baltimore the cost of vacuum filtration with chlorinated copperas as a coagulant would be $4.66 per ton of dry solids whereas it is now costing $6.23 on the drying beds.

Incineration.—Considerable progress is being made in the development of incineration methods for complete disposal of sludge and screenings, since it offers a satisfactory means for the destruction of all organic matter, leaving nothing but a residue of inert ashes. Initial dewatering by means of vacuum filters or presses is a necessary step before incineration can be economically accomplished. Different sludges have considerable heat value and records show that the B. t. u. values of digested sludge vary ordinarily between 4800 and 7200, of activated sludge from 6000 to 8000 and fresh solids from 6500 to 8500. When large quantities of industrial wastes or grit are present these values have even greater ranges. The auxiliary fuel may be either coal, gas or oil for complete combustion. At Chicago an experimental unit handling twenty tons of sludge daily (dry basis) is in operation. After first passing the sludge through vacuum filters, which produce a cake with 80 per cent moisture at the rate of 3 pounds per square foot per hour, a rotary drier carries the moisture content down to 20 per cent utilizing the waste heat from the combustion furnace. A small amount of coal is occasionally required. The use of a specially designed grate is important. The control of odors emanating from the incineration can be regulated by the adjustment of the burning temperature. At 1500° F. there was little odor, but from 300° to 500° F. the odors were pronounced.

Large scale operations of the disposal of sewage screenings by means of incineration are being conducted by the Westchester County Sanitary Sewer Commission. A typical installation is that at South Yonkers on the city line of New York City. Incinerators similar to those used in garbage disposal are utilized at Yonkers and also at Aurora, Illinois. Young[31] believes, however, that modifications of certain features of these incinerators might be advantageous. Both a water-jacket furnace type and a fire-brick furnace type, with fuel oil as the source of heat, are in operation, each having a capacity of one ton of screenings per hour when the water content is between the limits of 90 to 95 per cent. It requires approximately 25 gallons of oil per ton of screenings when the water content does not exceed 80 per cent. A higher fuel consumption has been noted for the water-jacket incinerator but the steam generated serves to heat the building. The minimum temperature for incineration is 1400° F. and the ash residue shows complete combustion to a finely divided material resembling thoroughly burned wood or paper ash.

Although no cost figures are available it is stated that incineration of screenings is entirely practicable and provides complete disposal at a reasonable cost and without nuisance.

A mechanical method of sewage treatment, obviating any biological treatment process, and providing for the ultimate disposal of sludge has been investigated on an experimental scale at the N. J. Sewage Experi-

ment Station, in coöperation with the Isbell-Porter Company of Newark, N. J.[22,23] Essentially, it consists of a series of tanks, filled with $1^1/_2$ in. slag through which the raw sewage is filtered upward. The sludge-covered slag is removed from time to time and incinerated in a specially designed calciner. The advantages of such a method are claimed to be simple and positive operation with complete disposal of sludge. It is stated that such a system may find a place as intermediate between plain sedimentation treatment and sedimentation plus trickling filters or activated sludge. Experimental results indicated that it would provide about 70 per cent removal of suspended solids and 55 to 60 per cent B. O. D. reduction but no persistent reduction in *B. coli*. If the raw sewage were given chemical treatment to remove finely divided and colloidal matter this system would give a higher degree of treatment, possibly to about 85 per cent removal of suspended solids, 85 per cent B. O. D. reduction and 95 per cent *B. coli* removal. Approximately 2 per cent of the slag was disintegrated to particles less than $^1/_2$ in. and the amount of ash per million gallons of domestic sewage containing 200 p. p. m. suspended solids was about 280 pounds.

Spray Drying.—The Industrial Associates, Inc., of New York, manufacturers of spray-drying equipment, have presented an adaptation of their process for the drying and eventual incineration of wet sludge. The principal parts of the apparatus are a drying chamber, a centrifugal spray machine, a furnace and a dust collector.

The sludge to be sprayed is stored in a tank from which it is fed into the spray machine and atomized in a horizontal plane near the top of the spray chamber. The dried product falls to the floor of the spray chamber and is collected by a revolving rake which delivers into a central chute, which discharges into a car or conveyor. The exit gases, reduced in temperature, and laden with moisture and a certain amount of the dust of the dried product are carried out of the drying chamber through the duct into a cyclone dust collector.[11] The dried product may be used for fuel in combination with coal to produce heat for drying one pound of dried sludge giving the equivalent of 5000 B. t. u. At a demonstration of this device at Poughkeepsie, N. Y., in 1931 the apparatus dried 3 gallons of sludge, moisture content 88 per cent, in one minute.

Centrifuging.—In Germany, centrifuges which are automatic in operation have been used for a number of years as a means of dewatering sludge. They have been considered expensive to operate and in the United States two cities, Milwaukee and Baltimore, have tested them in demonstration and experimental work.

Centrifugal machines have been used for many years in the sugar, oil and other industries to separate solids from liquids but it was not until 1902 that Herman Schaefer at Cologne, Germany, applied the centrifuge

principle for dewatering sewage solids. Schaefer enlisted the aid of Dr. Gustav ter-Meer in 1904 and together they developed the machine now known as the Schaefer-ter-Meer centrifuge, first installed at Frankfort-on-the-Main, Germany, and subjected to exhaustive tests. In 1914 many changes and improvements had been made, and in 1920 this machine was used at the Milwaukee activated-sludge plant operating at 1320 revolutions per minute. In 1922 another machine operating at 1700 revolutions per minute was tried. The chief difficulty with dewatering activated sludge was that it was impossible to get a clear effluent at an economical rate of application. In 1923 an improved centrifuge was sent to Baltimore,[18] at which time experiments were started The results of these tests indicated that this machine was simple in operation and the automatic devices worked satisfactorily. Digested sludge was more easily dewatered than either undigested or semi-digested material. The effluent was not of good character and had to be re-treated. The estimated cost of dewatering sludge by centrifuge was $1.33 per cubic yard to obtain a material of 71 per cent moisture content; with air-drying beds the cost was estimated to be $1.30 per cubic yard of 71 per cent moisture content.

Atlantic City Process.—Chester G. Wigley[27] at Atlantic City has patented a process for the disposal of sludge. The sewage is passed through settling tanks having a 30- to 45-minute detention period and the fresh settled solids are removed by centrifugal pumps to be distributed on regulation sand drying beds. When the mass is dry enough to be easily shoveled (moisture content 80 per cent) it is spread out on vacant land for further drying. When the air-dried sludge reaches a moisture content of 30 per cent it is broken up by machine methods and still in a moist state it is stored in a dark building where molds and fungi readily attach themselves to the mass. It is claimed that the growth of molds affects the solids so that there is no odor excepting that of musty earth.

Miles Acid Process.—The Miles acid process consists of the acidification of raw sewage with sulphurous acid and the extraction of grease from the resulting sludge. The acidification precipitates most of the suspended solids and also serves as a strong disinfectant to produce a highly sterilized effluent, but the chief merit claimed for this process was in the commercial value of the sludge produced. It was tried experimentally in Boston from 1911 to 1914 using sulphur dioxide gas. The salable value of the grease and the fertilizer base was estimated at $24 while the cost of chemicals and labor amounted to $18, leaving a profit of $6 per million gallons. The process was tested in 1917 and 1918 at New Haven, Conn., and the conclusion was reached that no financial return might be expected from the recovery of grease or fertilizer. In order to realize profit the sewage must have an exceptionally high grease content and low alkalinity.

Verdier or Sozymos Process.—This process has been utilized in France

and experimentally tried on garbage in Philadelphia. Sludge is mixed with garbage, placed in cells and inoculated with "Zymos," which appear to be a concentrated culture of enzymes produced on decomposition of the treated material. The object is to produce fertilizer. The cost, including amortization, is estimated at $1.36 per ton of wet solids. The time required is from 22 to 25 days. The process may be considered as an improved Beccari method.

Earp-Thomas Process.—The process is claimed to operate with the addition of strong bacterial cultures and ingredients, which makes the residue a better fertilizer. The time required for completion of the process is claimed to be less than 24 hours. The Earp-Thomas Process was investigated at Milwaukee and results indicated that very little decomposition of the solids was effected. (See THIS JOURNAL, p. 364, March, 1933.)

In both the Verdier and Earp-Thomas processes the sewage sludge must be dewatered so that the sludge can be readily handled and placed in cells.

Utilization of Sludge as a Fertilizer.—Sludge is a mild fertilizer which does not burn crops and due to its fibrous and porous structure conserves moisture, thus acting as humus. Human wastes and wastes from certain industrial processes contain essential plant food such as nitrogen, phosphoric acid and potash which are conserved to a certain degree in the sludge. Commercial fertilizers are made up to contain these ingredients in soluble forms which are easily assimilated by plant life. Sludge, on the other hand, combines these constituents with other substances, and bacterial action is required to break down these complex materials into simpler units useful for plant growth. In this respect it is similar to barnyard manure.

Fertilizing Value.—All sludges contain nitrogen, phosphorus and potash, but practically the only value as a fertilizer lies in the nitrogen content. This latter constituent varies with the type of treatment received by the sewage and ranges from a 5 per cent average content in dried activated sludge to a 2.25 per cent average content in well-digested sludges. Although well-digested sludge is necessary for rapid drying and freedom from odors, the fertilizing value is decreased the more the material is digested. On the other hand, this detrimental effect is partially offset by the fact that the spongy cake from well-digested sludge promotes porosity of soil. Undigested activated sludge has given the best results due to its high nitrogen content, which is commonly ascribed to the inclusion in the sludge of much of the nitrogen lost in the effluent of other treatment processes. In connection with this loss of nitrogen in the effluent, experiments conducted at Bedford, England, showed that 86 per cent more fertilizing value was found in liquid sludge from Imhoff tanks sprayed on land than from the dried cake.[6]

Preparation of Fertilizer.—In order to utilize sludge for the preparation of fertilizer it must be dried to a 10 per cent or less moisture content.[13] For this purpose rotary heat driers are employed, the sludge first being dewatered by mechanical filters to an 80 or 85 per cent moisture content. At Pasadena,[8] California, the activated-sludge plant has a capacity of 8 tons per day. This material analyzes 5 per cent total nitrogen, 2.4 per cent total phosphoric acid and 0.3 per cent potash. At Milwaukee approximately 100 tons of dry material is produced per day and analysis show that of the insoluble organic nitrogen, 5.42 per cent is in highly available form, and the sludge in addition contains 3.08 per cent phosphoric acid. Houston, Texas, has in operation a $200,000 plant for the manufacture of fertilizer and markets its product under the trade name of Hu-Actinite.[8] Air-dried sludge from glass-covered beds at Dayton, Ohio, has been dried further in a small rotary drier, ground in a hammer mill and sold locally. Many plants dispose of their digested sludges by selling it to farmers, orchardists, park boards, golf clubs, schools, greenhouses and florists at a nominal price of from 25 cents to $1.00 per ton.

Economic Considerations.—The economic aspect of sludge as a fertilizer is brought to our attention by Rudolfs,[24] who has stated that from 150,000 to 200,000 tons of nitrogen, as a conservative estimate, present in sewage is annually lost in the United States by discharging sewage into streams and watercourses and by wasting sludge. The preparation of fertilizer from activated sludge is a manufacturing process having a number of stages, which can be conducted profitably only on a large scale. Laboratory and field tests have proved that this substance is a good fertilizer and compares favorably with such organic materials as dried blood, tankage, fish scrap and cottonseed meal. Pasadena, California, sold its pulverized sludge and irrigated the municipal farm with a portion of the plant effluent, resulting in inquiries from farmers regarding the purchase of the remaining effluent. Smaller plants will undoubtedly continue to sell sludge, principally in order to get rid of the material.

Hygienic Considerations.—The use of sludge for fertilizing purposes raises the question of whether there is any danger of spreading typhoid and other diseases by this procedure. Practice in foreign countries shows general agreement that it is unwise to permit the application of wet sludge to food products that may be eaten raw. In America the public health authorities have adopted a similar attitude and particularly in California stringent regulations are in effect.

The viability of pathogenic bacteria, particularly *B. typhosus*, in connection with sewage-transmitted disease has been extensively studied by Kligler,[16] who found that typhoid bacilli could not be isolated after 8 days in moist soil and after 20 days in dry soil. The speed with which *B. typhosus* dies off in soil is chiefly dependent on the moisture content and

reaction of the soil. Wolman[30] states that in sewage sludge which has undergone normal digestion, the survival of the typhoid fever bacilli was probably less than 7 days. It is generally concluded that fertilizer manufactured through the process of heat drying may be considered hygienically safe.

Future Trends

From a general standpoint the objections against present methods of dewatering and final disposal of sludge are handling and cost. Wherever sludge is sold as fertilizer some form of a sales organization must be developed. This is of minor importance for small plants, but when large volumes of sludge are dried and sold a specific organization must take care of the product. The main objections to present methods of dewatering sludge, other than on sand filters, is the necessity of pre-treatment with chemicals. Methods applied and proposed require more or less accurate control, are comparatively complicated and are rather costly.

Methods of sludge disposal can be divided into two general parts: (1) preparation for ultimate disposal and (2) final disposal of the sludge.

In discussing future trends the size of treatment plant or the volume of sludge to be treated must be taken into consideration. As a rule sludge treatment and ultimate disposal at small plants with flows less than 1 m. g. d. is not very difficult, because most of such small plants are located sufficiently far from the municipality to have land available. The exceptions often have a higher degree of treatment. There seems to be no definite tendency at small plants located near or in built-up sections to remove the wet settled or digested sludge at very frequent intervals by means of tank cars, as is done in many cases abroad. Thus far the policy has been to treat and dry the sludge at the works, disposing of the air-dried material as cheaply and conveniently as possible. We are familiar with a few instances where removal of wet sludge—other than transporting it out to sea, as is done by several larger plants—has been practised, but little has been found in the literature regarding operation and cost. Future trends in preparation and ultimate disposal of sludge for larger plants may affect small plants, but probably to a small degree until simple and economical methods have been found.

Preparation of Sludge.—Preparation of settled (both fresh and activated) or digested sludge for ultimate disposal falls under three headings: (1) physical, (2) biological and (3) a combination of physical and chemical methods. The present available physical methods consist in general of sand filtration, vacuum filtration, pressing or centrifuging. The nature of the materials to be dewatered is such that none of these methods alone produces results quickly without troubles. Part of the water in the sludge is held so tenaciously that it can be removed only by evaporation or with

the aid of chemicals. Even after prolonged bacterial decomposition the salts and colloidal substances prevent rapid dewatering. Sand filtration, with or without covered and/or heated beds, is cumbersome, requires large areas and is costly. Nevertheless, many new plants will be built where this method is employed. Vacuum filtration, pressing and centrifuging without the aid of chemicals or other treatment is physically impossible so far, too difficult or too costly. No chemical method is known for dewatering sludge without the aid of filtration, pressing, centrifuging or other mechanical treatment. This applies also to inert materials such as infusorial earth, clay, paper, fibrous trade wastes and the like. Biological preparation (Beccari, Verdier, Earp-Thomas) for ultimate disposal depends upon fertilizer production and the success or failure from a financial point of view depends upon the fertilizer market and its fluctuations. It is clear that these processes introduce a factor or set of factors which cannot be controlled by the operator of the plant or the community. It is very likely that the majority of municipalities will be cautious before they venture into fertilizer production, unless the processes are operated under contract with a firm which will take the sludge off their hands and dispose of it. Other physical methods to prepare the sludge for ultimate disposal consist of hot air drying, treatment with steam, dialyzing, freezing, etc. Hot-air drying has been demonstrated in an experimental installation at Poughkeepsie, New York. Not much information is available on steam treatment of sludge outside of laboratory experiments. It appears that certain sludges dewater more readily when treated for a certain length of time, while others become more slimy and prevent dewatering almost completely. Steam treatment in combination with certain chemicals may be of interest. The effect of freezing on sludge is well known among operators. No one has proposed to freeze large quantities of sludge artificially as an aid in dewatering.

The vast majority of processes proposed for dewatering sludge utilize chemical preparations prior to filtration, pressing or centrifuging. In nearly all cases where inert substances such as clay, paper or fiber are used, chemicals are also added. The chemicals usually applied are iron salts, alum or lime. These chemicals are primarily coagulants and as such will release a certain quantity of water that can be removed comparatively easily. Large quantities of chemicals must be added in order to obtain a filter cake sufficiently dry to handle either for fertilizer production or incineration. A critical study of the results obtained indicate that along this line the limits are almost reached with our present knowledge of the action of these coagulants. To be sure, some improvement will result on further investigation, especially in the direction of returning flocculated sludge, which serves as a nucleus and contains a portion of the coagulant used. Investigations along these lines will probably show that somewhat

smaller quantities of chemicals may be used, but fundamentally no radical reduction in chemicals, greater ease of filtration or vastly thicker cakes, resulting in less and smaller equipment, seem foreshadowed. This means, necessarily, that the use of known coagulants alone, as a means of dewatering, is not the direction in which marked progress can be made in the future. A search for new and better coagulants for sludge may lead to better results at lower costs, but there is also a wide field for new coagulants for clarification of sewage.

Another group of trials and investigations deals with the use of fibrous substances in conjunction with coagulants.[9] This field has been investigated far less thoroughly than the use of coagulation alone. Practically no fundamental studies have been published embodying the use, combination and order of additions of inert substances and coagulants. The quantities of inert or fibrous substances and coagulants used at present are also far too great in most cases, but this may be due to lack of sufficient information rather than to inherent necessity for large amounts. It would appear that further investigations along these lines may bring improvement, especially if several coagulants are used in the proper order. However, as long as no fundamental studies are made dealing with the nature of the substances which hold the water, and interfere with the release of the water, only accidental discovery will bring forth anything worth while.

For a number of years sanitary chemists have been talking about the colloids in sewage. Some investigations have been made, notably in England, but the variety of attacks and methods used makes it very difficult at present to even indicate how much colloidal material is present in fresh solids, ripe or activated sludge, to say nothing about their characteristics. Colloid chemists have worked a good deal with pure substances and a mass of information is available. It probably would be as hopeless to determine the different colloidal substances in sludge and their behavior as it would be to isolate and study all bacterial strains present in sewage. We are interested in the mass, its gross behavior and results. More knowledge of the gross reactions will undoubtedly show entirely new lines of investigation.

Final Disposal.—The problem of final sludge disposal may be divided conveniently into three parts: (1) fertilizer production, (2) destruction, and (3) dumping or filling-in. In fertilizer production a distinction may be made between sludge as fertilizer from fresh solids, ripe sludge and activated sludge dried for the market to compete with other artificial fertilizers, and the drying of sludge for local use on farms, in greenhouses and on lawns. Sludge sold or given away locally from many small plants may conceivably have some effect upon the sale of fertilizer from large plants by stimulating a demand, but at the same time would take away—at least theoretically—a portion of the potential market. However, it is

probable that the utilization of sludge from small plants will be of little consequence in this respect. The vast majority of small plants employ, at present, settling and some form of digestion. A thorough survey of the potential possibilities of sewage and sludge treatment processes in use and proposed does not, at present, indicate a material difference in the trend. For many years to come, simple settling and digestion will be employed at many places, principally because the need of a high degree of treatment is not apparent, the operation is comparatively simple and the cost moderate. There is undoubtedly a demand for more, and in some cases for higher degree of treatment of sewage, but no chemical treatment has been evolved as yet which will replace in the near future simple sedimentation devices, with or without digestion, for small plants. The sludge produced from these small plants will be used locally for fertilizer, dumped or used for filling-in. Even if a more rapid, efficient method is devised to treat the sludge from small plants for drying purposes it is doubtful whether the final disposal will be different.

Fertilizer Production.—Probably the best analysis of fertilizer production which has been published in recent years is the report made by Townsend[26] upon the various phases of a sewage sludge processing plant for the Easterly Sewage Works, City of Cleveland, Ohio. He states that activated sludge fertilizers containing 4 per cent of nitrogen as NH_3 and 2 per cent of phosphoric acid is substantially comparable to a low grade fertilizer material. On the basis of Milwaukee experience he concludes that the expected fertilizer production at the Cleveland Easterly Works, with a flow of 104 m. g. d. in 1935 and 160 m. g. d. in 1980 of sewage containing 200 p. p. m. suspended solids (90 per cent retained), would be from 28,470 to 43,800 tons per year, requiring an operating personnel of 60 men and a total annual cost of disposal of $726,029 or $17.75 per m. g. d. The possible annual revenue from the sale of fertilizer was estimated to range between $333,581 and $674,520, depending upon the manner in which the fertilizer would be sold, but conditions most likely to exist would probably produce a total annual revenue of approximately $386,000. The cost of getting rid of the sludge would therefore be about $340,000 per year or about $7.90 per m. g. sewage on a basis of 120 m. g. d. flow. The method of dewatering and drying of the sludge would be similar to that practised at Milwaukee. If the profit estimated by Townsend can be realized the cost of disposing of the sludge would be about $11.05 per ton of dry solids, as compared with $6.23 at Baltimore (estimated by Keefer[14] for the years 1925 to 1931, inclusive), for air drying on sludge beds. The air-dried sludge must still be disposed of either by giving it away to farmers or by incineration.

The selling of fertilizer by cities naturally depends upon the fertilizer market. Townsend in his study came to the conclusion that the trend

of the future market for this character of material (dried sludge) as well as for the other organic nitrogen bases, should, from the latest forecast information, be upward.

This conclusion is primarily for activated sludge, with a comparatively high nitrogen content. The nitrogen content of activated sludge is on the average at least twice that of digested sludge. A study of the fertilizer markets show that the increase in sales of artificial fertilizer was very rapid between 1895 and 1911, but fluctuated greatly thereafter, with practically no increase. On the other hand production of synthetic nitrogen and ammonia by-products has increased very rapidly since 1910 and the capacity of the plants has increased greatly. It is somewhat questionable whether low grade fertilizers produced by cities, either as a base for a complete fertilizer or sold as such, would be economical during the near future. Undoubtedly much more fertilizer could and will be used, but with the available information the fact that sales organizations must be set up, which may be influenced frequently by local political changes, the unwillingness of communities to go in for production processes, coupled with the probability that fertilizer manufacturers would make an energetic campaign against this competition, it is doubtful whether fertilizer production will be adopted on a large scale by many communities in the near future.

Destruction.—Dewatering of sludge with or without the help of chemicals on vacuum filters, on stone or on sand, preparatory to ultimate destruction, will probably develop more rapidly during the next few years than improvement in incinerators now commonly used for garbage destruction. At present incinerators are used where either screenings alone or sludge mixed with garbage is burned, but the requirements for dewatered sludge produced as cake or in a more or less powdery form are somewhat different. The experiments made by some industrial firms and in particular by the Sanitary District of Chicago indicate the direction in which to go. Engineers are much interested in dewatering and incineration because it would appear that the difficult sludge disposal problem may be solved permanently, efficiently and possibly at lower cost. However, much work remains to be done before the goal is attained.

Summary

Methods for sludge handling and disposal have not kept pace with other advances in sewage treatment and to the chemist, engineer and equipment manufacturer offer a fertile field for development.

It is reasonable to state that the present accepted status of sludge disposal by means of drying beds, and final disposal on land or at sea may be considered only temporary or transitory until more desirable methods are utilized.

The production of fertilizer is a satisfactory means of disposal, but is limited by the economic aspects of market and price. Profitable installations for fertilizer production can only be installed at the larger plants and is even questionable there if development would be rapid. Furthermore, the production of fertilizer requires a form of sewage treatment where the nitrogen is conserved, which necessitates identification with treatment of sewage to a greater degree than is sometimes necessary for good stream conditions. For smaller plants, and at places where the sludge is digested, only local use of the sludge as fertilizer can be made, unless a more organized effort is made to dispose of this material.

Investigations and large scale operations have shown the workability and to a certain extent the economics of dewatering sludge followed by incineration, but large quantities of chemicals are necessary for satisfactory dewatering and the expense is great. It appears that the use of known chemicals for dewatering (coagulants) is limited and either other chemicals must be utilized or a different line of attack made before dewatering can become universal. The two general lines of attack which suggest themselves are: (1) suitable filtration of sewage (without sedimentation, digestion, etc.) with or without a fixed medium, followed by incineration, and (2) sedimentation (with or without digestion), followed by dewatering along lines utilizing materials which change the surface tension, cause rapid base exchange, remove interfering substances and free the water held by the sludge rapidly.

Improved incineration will undoubtedly rapidly follow better and more economical dewatering methods.

It is apparent that the present methods of sludge treatment and disposal will be in continued use for a number of years to come, especially at the smaller plants where no local conditions make it imperative to follow new and more complicated methods.

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Some Effects of Sewage Chlorination Upon the Receiving Stream*

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"The proof of the pudding is in the eating" is an old adage which is often used to emphasize the difference between the theoretical and the actual, between the academic and the practical. In the engineering sciences we may apply it to the verification on a working basis of results indicated by analytical and laboratory procedures. Fortunately, engineering science is so nearly exact that we may usually have assurance that the findings in our computing rooms and laboratories may be successfully applied in practice—but not always so. It sometimes happens that such preliminary indications are misleading or untrue, due either to false hypotheses, errors in technique and procedure, or the failure to consider factors which have an important bearing on the problem. The recipe may appear tempting on the printed page, but, because of the lack of some necessary ingredient or faulty compounding and baking, the pudding may fail to come up to our gustatory expectations.

Previous Findings

Four years ago one of the authors of this paper presented the results of a very thorough study of the effect of various dosages of chlorine on the biochemical oxygen demand of settled sewage. This investigation was made under ideal conditions and with the utmost precision, on a plant-scale basis, by determining the B. O. D. of sewage effluent samples taken simultaneously from stations just above and just below the point of chlorine application. In this way samples were secured which were identical in all respects except for the applied chlorine. With proper precautions in laboratory technique, such as dechlorination and reseeding of dilutions of chlorinated sewage, it was found that chlorination of Chapel Hill settled sewage in sufficient amount (8 to 15 p. p. m.) to give a minimum free chlorine residual of 0.2 p. p. m. after a 10-minute contact period, resulted in a diminution of the 5-day, 20° C., biochemical oxygen demand to the extent of 25 to 40 per cent. Longer incubations of B. O. D. sub-samples confirmed the permanency of this effect and disproved the suspicion that

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delayed bacterial activity in the chlorinated portions was responsible for the phenomenon. It seemed to be a real, rather than an apparent, destruction of some of the oxidizable organic material in the sewage.

At about the same time, and subsequently, other investigators submitted data which have substantiated our findings, and, to a surprising and satisfying degree, have checked our results as to permanency of B. O. D. reduction, as to efficiencies obtained with given dosages and residuals and as to the limitations of this treatment process. It now appears to have been demonstrated to the satisfaction of the most conservative and critical sanitarians that chlorine, when properly applied in proper amounts, may be depended upon to reduce the oxygen demand of the organic non-settleable constituents of sewage by an average of 25 to 35 per cent, *as measured by the conventional B. O. D. determination on the unchlorinated and chlorinated waste.* But what is the actual and practical effect of such treatment upon the receiving stream? After all, we treat such wastes to relieve conditions of pollution or contamination in the receiving body of water, and unless the use of chlorine effects an improvement commensurate with its cost and trouble, it is a vain and wasteful process. Is it barely possible that the effects which we observe in our incubated B. O. D. bottles in the laboratory are only apparent or ephemeral, quickly to disappear when the chlorinated effluent is discharged into the stream, where it finds a new and complex environment in which all the many agencies of self-purification are busily at work—physical, chemical and biochemical agencies, ranging from dilution to intense biological antagonisms?

During much of the time for the past four years we have been working in a very modest way at the University of North Carolina to determine whether the practical benefits of chlorination check the laboratory findings. In many ways the situation at Chapel Hill is ideal for conducting a study upon the effects of sewage chlorination on the receiving stream, but our disappointments during these many months have proved the difficulties of such an investigation and offered an explanation for the paucity of reliable data on this question. So far as we know, this is the first long-time, scientifically conducted study of its kind, and it is hoped that the data here presented may be of some value to the profession and serve as the basis for further investigations by other agencies. Without attempting to indulge in chemical or biological explanations of observed phenomena, we desire to present in this paper a brief report of our findings and to mention some of the many variable factors which made the study such a difficult one.

Approach to the Problem

We had to take conditions as we found them. The stream studied was of widely varying quality and temperature, subject to extreme conditions

of flow, ranging between virtual stagnation in times of drought to scouring velocities in flood periods sufficient to disturb sludge deposits and upset completely the chemical and biological equilibrium. The stream had a tortuous channel of non-uniform gradient and cross-section, expanding at some places into extensive pools and wild swamps which made impossible an even approximate determination of velocity at different stages and prevented the establishment of sampling stations at strategic down-stream points. The sewage, while strictly domestic in nature and from a fairly uniform population, was subject to rather wide natural variations in hourly and daily dry-weather flow and quality, which fluctuations were further accentuated by heavy infiltration in times of storm. Changes in temperature, humidity, sunlight and wind velocity gave rise to additional variable factors. It can be seen that it was impossible to approach the ideal of having constant all factors, *except chlorination*, which affect self-purification and the oxygen balance of the stream. The best that we could do was to choose periods for the study in which minimum changes in these many factors were likely to occur.

The Chapel Hill Situation

The sewage from the town of Chapel Hill and the University of North Carolina is strictly domestic, of reasonably uniform flow and quality and comes from a population of about 5000 people. The average daily flow is about 350,000 gallons. Due to a long outfall sewer with flat gradient, the sewage usually reaches the treatment works devoid of oxygen, but, except during the most severe summer temperatures, septic action has not usually progressed to the point of active hydrogen sulphide production. The sewage treatment plant at the time of this study consisted of coarse bar screens, grit chamber, circular Imhoff tank and sludge beds. Bolin Creek, the stream receiving the settled sewage, has a normal dry weather flow of about 1.5 to 2.0 m. g. d., but in periods of extreme drought, such as have been experienced for the last three summers, the flow often falls below 100,000 gallons per day. Its watershed of about 10 sq. mi. above the sewer outfall is practically uninhabited, and the water at the point of sewage discharge is relatively unpolluted, having a 5-day B. O. D. usually not over 1.0 p. p. m. Below the outfall the sluggish stream flows several miles through uninhabited country without any great augmentation of flow or pollution from tributaries. Consequently, the organic burden of the stream is limited to that contributed by the Chapel Hill sewage. Except for swampy conditions previously mentioned, this stream is fairly well adapted to studies of the progress and extent of self-purification processes and the estimation of any effects produced by the chlorination of tributary sewage.

Plan of the Experiment

In order to measure the sewage flow accurately and determine its fluctuations a weir chamber was built into the effluent line between the sedimentation unit and the stream and equipped with a Gurley recording stage register. A dam was constructed of sheet-piling across the stream a few

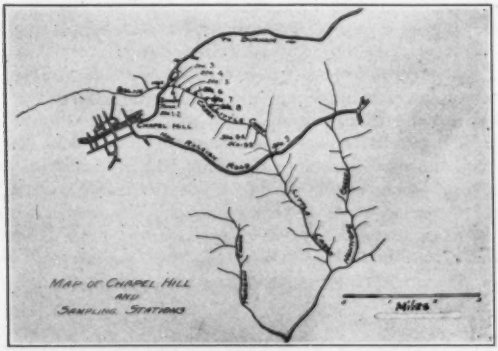

FIG. 1.—Locations of Sampling Stations.

hundred feet above the sewer outfall and fitted with a rectangular weir of sufficient size to measure with exactness the dry-weather flow of the creek. Rainfall records were obtained from the local Weather Bureau Station operated by the Water Resources Division of the North Carolina Department of Conservation and Development. Sampling stations were established at the following locations:

Station 1.	Imhoff tank effluent before chlorination
Station 2.	Imhoff tank effluent after chlorination
Station 3.	Stream 200 feet above sewer outfall
Station 4.	Stream 600 feet below outfall
Station 5.	Stream 1600 feet below outfall
Station 6.	Stream 2500 feet below outfall
Station 7.	Stream 3000 feet below outfall
Station 8.	Stream 1 mile below outfall
Station 8A.	Stream $2^1/_2$ miles below outfall (temporary)
Station 8B.	Stream 3 miles below outfall (temporary)
Station 9.	Stream 4 miles below outfall

In order to study the effects on the receiving stream produced by chlorination of the tributary sewage, the general plan of procedure adopted comprised the following cycles: (*a*) Chlorinate the settled sewage to maintain a

given residual for a period of a week to allow for the establishment of biochemical equilibrium in the stream for this condition. (*b*) With chlorination continued at the same rate, sample daily, for physical, chemical and biological examination, the unchlorinated and chlorinated effluent and the receiving stream at several points for a distance of ¼ miles below the outfall, for the period of a week. (*c*) Stop chlorination and sampling for one week to allow for the reëstablishment of biochemical equilibrium for the unchlorinated condition. (*d*) Sample daily for examination the unchlorinated effluent and stream at the same time and points for the period of one week. For about three years these experimental periods were carefully chosen on the basis of anticipated weather conditions, and the cyclic examinations conducted—all too often, alas, in vain!

The daily routine consisted of observations on sewage and stream flow, weather conditions, air temperature, rate of chlorine application, 10-minute chlorine residual, the collection of samples from each of the stations listed above for physical, chemical and bacterial determinations and the conduct of these tests in the laboratory. A rigid time schedule was adhered to, which provided for observations and sampling at each station at the same time each day throughout the entire period of the investigation, in the hope that by this procedure many experimental errors and variable factors would be compensated. Unusual precautions were taken in sampling, transportation and storage of samples, and in laboratory technique, to insure the highest possible accuracy of results. At each station observations were made for temperature, physical appearance, odors and aquatic life; and the samples collected were examined for pH, dissolved oxygen, biochemical oxygen demand, total bacteria on agar at 37° C. and *B. Coli* (partial confirmation). With the elimination of periods of adverse rainfall and temperature conditions, the study was carried on during the collegiate years of 1928, 1929 and 1930, and complete observations were made on a total of 111 days. Due to the fact that field-work was done by graduate research students who were in residence at the University only during the school year, it was impossible, prior to 1930, to continue these investigations during the summer months when natural conditions for the study were at their best. However, during the summer of 1930 arrangements were made, fortunately, for the continuance of the experiment during the hot and dry months of August and September.

Results

During the first two years the results of the study were disappointing and discouraging. In spite of our judicious choice of sampling periods, based on the expectancy of normal weather prevalence in the region, rainfall and temperature conditions were such as to cause extreme and rapid variation in the numerous factors governing stream self-purification, which it was

desired to keep constant. Often an experimental cycle would be almost completed under comparable conditions of sewage and stream flow and quality, temperature and sludge deposits, when heavy rainfall would cause a flood condition in the stream which upset completely the biochemical

TABLE I

RAINFALL, SEWAGE AND STREAM FLOWS AND TEMPERATURES

Date 1930	Rainfall, Inches. Previous 24 Hrs.	Mean Sewage Flow in 1000 Gals./Day	Stream Flow in 1000 Gals./Day	Temperature, °C., 9 A.M. at Stations* Air	1-2	3	4	5	9
May 9	0.00	315	...	26.5	19.5	21.5	21.5	21.5	24.5
10	0.04	325	...	27.0	19.0	21.0	21.0	21.2	..
13	Tr.	350	...	30.0	22.0	21.0	23.0	24.0	21.5
17	0.00	315	...	29.0	20.0	20.0	20.5	20.0	20.0
20	0.00	320	...	29.0	20.5	22.5	22.2	23.0	23.5
22	0.00	315	...	25.0	20.5	20.0	21.0	21.0	21.0
24	Tr.	335	...	30.0	22.0	23.5	23.0	23.5	24.0
29	0.00	320	...	20.0	20.0	20.0	20.5	20.5	..
Aug. 8	0.10	363	616	30.0	24.5	25.0	25.5	25.0	25.0
9	0.00	363	583	34.0	24.5	26.0	27.0	27.0	29.0
11	Tr.	332	800	30.0	23.0	23.5	25.0	25.0	28.0
12	0.00	298	616	23.0	23.0	20.0	23.5	23.5	25.0
13	0.00	298	583	25.0	22.5	21.0	22.0	22.5	24.0
14	0.00	298	583	24.0	23.0	20.0	21.0	21.5	22.5
15	0.23	298	816	22.0	23.0	20.5	21.5	21.5	21.5
16	0.00	282	700	28.0	23.5	21.5	22.5	22.5	23.0
19	Tr.	282	758	..	22.0	20.5	22.0	22.0	23.0
20	0.00	282	700	25.0	22.0	20.5	21.5	22.0	23.0
21	0.00	309	583	22.0	22.0	20.0	21.0	21.0	22.0
22	Tr.	309	545	18.0	22.0	20.0	20.5	20.5	20.5
23	0.00	363	545	20.0	22.0	19.5	19.5	19.5	20.0
24	0.00	309	545	22.0	22.0	18.0	21.0	21.5	22.0
25	0.00	363	472	24.0	21.5	17.0	21.5	22.0	21.0
27	0.00	332	340	25.0	22.0	19.0	22.0	22.0	22.0
28	0.00	332	275	25.0	22.0	18.5	21.5	21.5	21 0
29	0.00	332	275	25.0	22.0	19.0	21.5	21.5	21.0
30	0.00	265	260	27.0	22.0	20.0	22.0	22.0	22.0
Sept. 1	0.00	233	123	28.0	22.0	20.0	23.5	23.5	23.0
2	0.00	298	104	28.0	22.0	22.0	23.5	23.5	25.0
3	0.00	233	80	28.0	22.0	21.0	23.5	23.5	25.5
4	0.00	265	59	26.0	22.0	22.0	23.5	23.5	25.0
5	0.00	205	59	29.0	22.5	24.0	24.0	24.5	..
6	0.00	233	59	28.0	22.5	22.5	24.0	24.0	25.0
Mean	..	305	443	26.0	22.0	20.6	22.3	22.4	23.1

* Locations of Stations:

Station 1—Imhoff tank effluent
Station 2—Imhoff tank effluent, chlorinated
Station 3—Stream, 200 ft. above sewer outfall
Station 4—Stream, 600 ft. below sewer outfall
Station 5—Stream, 1600 ft. below sewer outfall
Station 9—Stream, 4 miles below sewer outfall

TABLE II

THE EFFECT OF CHLORINATION ON OXYGEN CONDITION IN STREAM

Date, 1930	Chlorine Application, P. p. m.	Residual Chlorine, P. p. m.	Dissolved Oxygen, P. p. m., at Stations* 1-2	3	4	5	6	7	8	9
May 9	0.0	...	0.4	9.3	1.8	3.5	..	..	..	4.4
10	0.0	...	0.7	9.3	5.3	4.5	4.5	..	..	3.5
13	0.0	...	0.0	9.1	5.1	4.6	4.8	..	..	4.1
17	0.0	...	0.0	9.0	4.0	3.9	3.0	..	..	3.5
20	0.0	...	0.0	7.4	3.4	3.0	2.7	..	..	3.4
22	0.0	...	0.0	8.6	3.3	2.7	2.8	..	..	..
24	0.0	...	0.0	8.4	4.6	3.3	2.1	..	..	..
29	0.0	...	0.0	9.2	3.6	2.9	2.0	..	..	5.1
Aug. 8	0.0	...	4.1	7.7	1.4	1.3	..	..	..	3.3
9	0.0	...	3.6	7.4	2.0	0.8	..	..	1.5	5.6
11	0.0	...	5.9	8.9	3.7	3.2	2.0	..	..	5.1
12	0.0	...	2.3	7.4	3.7	1.9	1.5	..	..	5.4
13	0.0	...	0.6	8.1	5.1	4.2	1.8	..	..	4.6
14	0.0	...	4.7	7.2	4.6	3.0	2.7	2.9	..	4.8
15	0.0	...	0.4	6.8	4.3	3.0	2.7	2.8	..	4.1
16	0.0	...	0.5	7.5	5.7	4.6	4.0	3.9	..	3.9
19	9.8	2.0	0.0	7.1	7.9	6.2	6.0	5.4	..	3.9
20	9.8	2.0	0.0	7.2	7.0	6.2	5.5	4.2	..	4.6
21	9.3	2.0	0.0	7.1	6.4	6.0	4.5	3.0	..	4.9
22	15.5	1.3	0.0	6.7	6.6	6.3	5.5	4.7	2.8	4.0
23	13.2	0.5	0.0	7.2	6.7	6.9	6.5	5.7	5.0	4.9
24	15.5	1.5	0.0	8.1	7.7	7.2	6.9	6.2	..	4.6
25	13.2	0.6	0.0	6.8	6.5	6.8	6.4	5.7	..	4.0
27	0.0	...	0.0	6.1	2.8	1.5	1.2	1.0	1.8	3.7
28	0.0	...	0.0	6.0	3.6	1.9	2.1	2.2	2.7	3.5
29	0.0	...	0.0	6.3	3.6	1.6	1.3	1.4	2.2	3.3
30	0.0	...	0.0	5.9	3.3	1.1	1.0	1.2	2.1	3.6
Sept. 1	20.6	4.0	0.0	5.8	6.6	5.8	5.7	5.0	3.1	4.6
2	15.5	4.0	0.0	5.2	6.1	5.9	5.4	4.3	2.2	5.2
3	20.0	4.0	0.0	5.1	6.1	5.7	5.3	3.5	2.0	6.0
4	0.0	...	0.0	4.6	2.9	1.2	1.6	1.9	2.9	5.1
5	0.0	...	0.0	7.7	2.4	0.0	1.2	1.1	1.6	..
6	0.0	...	0.0	6.7	2.7	1.2	1.2	1.5	2.9	7.3
Mean Unchlorinated	..	...	0.7	7.3	3.60	2.56	2.31	1.99	2.21	4.36
Mean Chlorinated	14.2	2.2	...	...	6.76	6.30	5.77	4.77	3.02	4.67

NOTE: Average Chlorine demand for period, 12 p. p. m.

* Location of Stations:

Station 1—Imhoff tank effluent
Station 2—Imhoff tank effluent, chlorinated
Station 3—Stream, 200 ft. above sewer outfall
Station 4—Stream, 600 ft. below sewer outfall
Station 5—Stream, 1600 ft. below sewer outfall
Station 6—Stream, 2500 ft. below sewer outfall
Station 7—Stream, 3000 ft. below sewer outfall
Station 8—Stream, 1 mile below sewer outfall
Station 9—Stream, 4 miles below sewer outfall

TABLE III

THE EFFECT OF CHLORINATION ON BIOCHEMICAL OXYGEN DEMAND CONDITION IN STREAM

Date, 1930	Chlorine Application, P. p. m.	Residual Chlorine, P. p. m.	Biochemical Oxygen Demand, P. p. m., at Stations* 1	2	3	4	5	6	9
May 9	0.0	...	280	...	0.9	33	24	...	5.0
10	0.0	...	118	...	1.4	18	15	13	4.0
13	0.0	...	171	...	0.5	28	23	17	5.0
17	0.0	...	172	...	0.5	25	36	31	4.3
20	0.0	...	174	...	3.5	31	33	23	4.8
22	0.0	...	155	...	0.8	34	26	22	...
24	0.0	...	170	...	0.8	26	23	17	...
29	0.0	...	165	...	1.0	30	26	21	4.5
Aug. 8	0.0	...	258	...	1.0	42	28	...	3.9
9	0.0	...	157	...	0.7	33	25	...	3.0
11	0.0	...	181	...	0.8	22	8	14	1.5
12	0.0	...	114	...	0.8	16	9	11	4.5
13	0.0	...	92	...	0.9	18	10	5	1.6
14	0.0	...	97	...	1.3	12	8	7	3.8
15	0.0	...	86	...	1.0	9	8	7	3.0
16	0.0	...	119	...	1.4	12	6	4	4.6
19	9.8	2.0	76	38	1.6	13	13	12	4.7
20	9.8	2.0	65	41	1.8	12	10	10	2.2
21	9.3	2.0	35	28	1.3	22	13	10	2.8
22	15.5	1.3	119	65	1.5	3	1	12	3.1
23	13.2	0.5	80	48	1.0	23	1	3	4.0
24	15.5	1.5	89	43	1.3	1	1	1	3.3
25	13.2	0.6	143	101	0.9	24	2	15	2.4
27	0.0	...	83	...	1.0	27	14	12	2.9
28	0.0	...	43	...	1.0	21	9	8	3.2
29	0.0	...	50	...	0.4	25	11	8	3.2
30	0.0	...	39	...	0.3	12	5	4	2.9
Sept. 1	20.6	4.0	22**	0.0**	0.9	0**	0**	0**	2.0
2	15.5	4.0	50**	0.0**	0.9	0**	0**	0**	2.2
3	20.0	4.0	64**	0.0**	1.2	0**	10	11	2.8
4	0.0	...	41	...	1.2	13	8	7	2.4
5	0.0	...	108	...	1.1	33	22	19	...
6	0.0	...	112	...	1.1	23	9	6	2.6
Mean Unchlorinated			113	...	1.08	23.6	16.8	12.2	3.53
Mean Chlorinated	14.2	2.2	...	52.0	...	14.0	6.37	9.25	2.95

* Locations of Stations:

Station 1—Imhoff tank effluent
Station 2—Imhoff tank effluent, chlorinated
Station 3—Stream, 200 ft. above sewer outfall
Station 4—Stream, 600 ft. below sewer outfall
Station 5—Stream, 1600 ft. below sewer outfall
Station 6—Stream, 2500 ft. below sewer outfall
Station 9—Stream, 4 miles below sewer outfall.

** Results Disregarded.

equilibrium and rendered valueless all of the data collected in the previous phases of the cycle. Sudden changes in temperature would likewise disturb the comparison and interpretation of results, since we had not been able to establish the velocity and re-aeration factors on this small sluggish stream of non-uniform channel and slope conditions.

During the summer of 1930, however, we were fortunate indeed in having conditions for several weeks as nearly ideal as could ever be expected. There was practically no rainfall for a period of three months, resulting in a low and gradually decreasing stream discharge; the tributary domestic population was constant; and the temperature was high and fairly uniform for the entire time. During a six-week period careful observations and determinations, except for bacteria, were made daily, yielding 33 series of results. For obvious reasons the period of the sampling cycle described above was shortened. Although there are some discrepancies in the results obtained, they were obtained under the best possible conditions and it is believed that they are sufficiently accurate as to be unquestionably convincing. So much faith is placed in their veracity that the authors are led to omit from the oxygen data submitted herewith the 78 other series of results that are undoubtedly marked by interfering factors. The bacteriological data submitted in this report are for the period February 13 to April 26, 1930. Owing to the fact that only one man was engaged in the study in the summer of 1930, it was impossible to carry on the bacterial determinations.

Discussion of Results

As indicated by the tabulated data, the average temperature of the air (9 A.M.) during the period of oxygen investigation in the summer of 1930 was 26.0° C. The corresponding average temperatures of the sewage and stream water at the various stations were as follows: Sta. 1–2, 22.0° C.; Sta. 3, 20.6° C.; Sta. 4, 22.3° C.; Sta. 5, 22.4° C.; Sta. 9, 23.1° C. The average mean daily flow of sewage was 305,000 gallons, and the mean daily discharge of Bolin Creek at the outfall was 443,000 gallons. The average rate of chlorine application during chlorination periods was 34.75 lb. per day, equivalent to a dosage of 14.2 p. p. m. The average residual after 10 minutes' contact was 2.2 p. p. m., giving a mean chlorine demand for the summer period of 12.0 p. p. m., a value about twice that found during the cooler months of early spring. The average 5-day, 20° C., B. O. D. of the settled sewage for the period was 113 p. p. m., and, while its content of dissolved oxygen was usually zero, the average for the period was 0.7 p. p. m. The water of the stream is low in dissolved mineral content, having a hardness of about 35 p. p. m., an alkalinity of about 30 p. p. m. and an average pH value of 7.2.

The time of flow of the stream from the outfall to the various down-

TABLE IV

THE EFFECT OF CHLORINATION ON TOTAL BACTERIA AND COLON BACILLI

Date, 1930	Chlorine Application, P. p. m.	Chlorine Residual, P. p. m.	Total Bacteria, Agar, 37° C., at Stations* 1	2	3	4	5	9	*B. Coli*, Partially Confirmed, at Stations* 1	2	3	4	5	9
Feb. 13	0.0	...	340,000	....	20	60,000	....	100	10,000	....	1	1,000	...	100
14	0.0	...	210,000	....	500	10,000	....	210	10,000	....	1	1,000	...	1
15	0.0	...	90,000	....	110	37,000	7,300	220	10,000	....	1	1,000	1,000	10
17	0.0	...	441,000	....	6	13,000	....	10	10,000	....	0	10	...	10
18	0.0	...	140,000	....	5	5,000	....	50	10,000	....	1	10,000	...	1
19	0.0	...	457,000	....	50	52,000	....	100	10,000	....	0	10,000	...	100
20	0.0	...	169,000	....	105	150,000	....	1,000	10,000	....	0	1,000	....	10
21	0.0	...	369,000	....	16	80,000	....	300	10,000	....	1	1,000	...	1
24	5.0	0.1	.....	32,000	90	20,000	....	30	....	1,000	1	100	...	0
25	5.3	0.1	.....	105,000	14	27,000	....	150	....	10,000	1	1,000	...	0
26	6.5	0.1	.....	21,000	18	0	....	70	....	10	1	0	...	1
27	5.7	0.2	.....	117,000	17	19,000	....	100	....	1,000	0	0	...	0
28	6.6	0.1	.....	4,000	87	700	....	1,000	....	10	10	10	...	1
Mar. 4	0.0	...	1,120,000	....	190	105,000	....	13,400	100,000	....	0	10,000	...	10
5	0.0	...	417,000	....	40	112,000	....	2,100	10,000	....	10	100	...	100
6	0.0	...	275,000	....	70	96,000	61,000	2,200	10,000	....	1	1,000	1,000	100
8	0.0	...	242,000	....	130	43,000	41,000	2,300	10,000	....	100	10,000	1,000	100
10	0.0	...	120,000	....	35	11,000	71,000	170	10,000	....	1	100	100	1
11	0.0	...	332,900	....	53	41,000	89,000	320	100,000	....	1	1,000	10,000	10
13	0.0	...	290,000	....	5	120,000	190,000	380	100,000	....	0	1,000	10,000	10
25	8.7	0.1	.....	200	82	17,000	500	1,800	....	100	1	10,000	0	1
26	8.3	0	.....	13,000	30	200	100	...	....	100	1	0	0	...
27	8.8	1.0	.....	100	35	0	800	110	....	10	10	0	0	1
28	8.8	0.1	.....	200	42	1,000	0	200	....	0	10	0	0	1
31	8.4	0.1	.....	2,000	11	200	0	100	....	1,000	0	10	0	0

Apr. 1	8.9	0.1	.....	1,000	10	800	200	100	....	100	1	1,000	0	1
2	9.3	0.1	.....	1,000	20	0	0	20	....	100	1	10	0	10
3	0.0	...	420,000	....	52	17,000	323,000	420	10,000	....	1	10,000	1,000	1
4	8.1	0	.....	23,000	500	2,000	1,100	1,400	....	100	10	100	0	10
5	8.7	Tr.	.....	44,000	50	3,000	5,000	110	....	100	10	0	0	10
8	8.1	0.1	.....	3,000	35	1,000	1,000	5,000	....	100	10	0	0	1
9	7.7	0.05	.....	106,000	19	0	0	0	....	1,000	0	0	0	0
10	7.7	0.05	.....	25,000	50	0	400	130	....	100	1	10	0	1
11	8.2	0.05	.....	18,000	90	0	700	1,650	....	10,000	0	0	10	1
12	9.6	0.05	.....	144,000	8	4,000	2,000	40	....	100,000	1	0	0	1
15	10.3	0.05	.....	5,000	6	300	200	1,200	....	100,000	1	10	10	10
16	10.0	0.05	.....	2,000	160	18,000	18,000	1,300	....	0	1	10	10	10
17	10.1	Tr.	.....	27,000	80	26,000	20,000	1,300	....	100,000	10	1,000	1,000	10
21	0.0	...	300,000	....	160	30,000	64,000	400	100,000	....	1	1,000	10,000	10
22	0.0	...	450,000	....	260	56,000	44,000	50	100,000	....	1	10,000	10,000	100
23	0.0	...	500,000	....	17	110,000	70,000	80	100,000	....	1	1,000	10,000	10
25	0.0	...	850,000	....	51	117,000	28,000	580	100,000	....	10	1,000	10,000	100
26	0.0	...	680,000	....	110	100,000	32,000	700	10,000	....	1	1,000	1,000	100
Mean Unchlorinated	...	...	391,000	....	104	65,000	85,000	1,200	40,000	....	5	3,450	5,400	42
Mean Chlorinated	8.13	0.12	.....	31,500	...	6,400	2,950	750	....	14,750	...	600	60	3

* Locations of Stations:

Station 1—Imhoff tank effluent, unchlorinated
Station 2—Imhoff tank effluent, chlorinated
Station 3—Stream, 200 ft. above sewer outfall
Station 4—Stream, 600 ft. below sewer outfall
Station 5—Stream, 1600 ft. below sewer outfall
Station 9—Stream, 4 miles below sewer outfall

stream stations depends, of course, upon the stage. Owing to conditions previously described, it was impossible to measure, or even approximate, the velocity.

It seems likely, however, that in times of severe drought several days may elapse in passage from the outfall to Station 9, four miles downstream.

Physical Appearance.—Perhaps the greatest effect of chlorination was in the improved physical appearance of the stream channel. During periods of non-chlorination luxurious growths of gray, slimy, filamentous organisms would attach themselves to every possible projecting object on the bed and banks of the channel and grow to great lengths, waving in the flowing current. In pools and dead areas of the swampy region the microorganisms characteristic of polluted water grew in great abundance. While these growths are probably highly beneficent from the standpoint of self-purification, they are very objectionable to the eye and would certainly constitute the major objection on the part of a riparian land owner or the non-scientific layman hell-bent on aesthetics. Usually the bottom and banks of the stream channel were heavily coated with a murky-black gelatinous deposit giving to the flowing water an untrue and very disagreeable appearance.

During periods of chlorination there was a remarkable improvement in the aspect of the stream. The filamentous growths sloughed off from their attachments and were washed down-stream. The littoral and free-floating types of algae practically disappeared, and the discoloring gelatinous growths released their hold upon the bed of the channel, making the water appear clearer and cleaner and revealing the clean sand and stones of the bottom. Moreover, chlorination seemed to have a marked effect upon the coagulation and sedimentation of suspended and colloidal materials of the stream water, as evidenced by a considerable reduction in turbidity during periods of chlorine application. When chlorination of the sewage was suspended, the growths and discoloration quickly returned.

Odors.—During periods of high temperature, when sewage reached the treatment works devoid of dissolved oxygen, the local odor condition was very obnoxious where there was slight aeration at the effluent weir of the Imhoff tank and at the point of discharge into the creek. During periods of chlorination this condition completely disappeared, the only perceptible odor being a slight, sweet, grassy one which was not objectionable. Since there was not a septic condition at any sampling point in the stream during the study, no hydrogen sulphide odors were observed. However, a distinct earthy odor occurring along the stream during non-chlorination disappeared during the administration of chlorine. In hot weather there was extreme nuisance from the non-settleable scum on the flow chamber of the Imhoff tank, which it was found could be largely dis-

pelled by pre-chlorination of the raw sewage in sufficient amount to yield a trace of residual chlorine in the tank effluent.

Dissolved Oxygen.—In Table V is presented a recapitulation of the dissolved oxygen data for the summer period of 1930, and these results are shown graphically in the chart of Figure 2.

TABLE V

RECAPITULATION OF DISSOLVED OXYGEN RESULTS

Station	Average D. O., Per Cent Saturation Unchlorinated	Chlorinated	Per Cent Change by Chlorination
1–2	8.0	..	...
3	81.0	..	...
4	41.0	76.4	86.4
5	29.0	71.2	145.5
6	26.5	65.6	147.5
7	21.9	54.2	147.3
8	26.0	35.0	34.6
9	51.0	53.7	5.3

Average chlorine dose, 14.2 p. p. m.
Average chlorine residual, 2.2 p. p. m.

It will be observed that for the period the average D. O. content of the effluent sewage was 8.0 per cent of its saturation value. This was, of course, not changed by chlorination. The stream above the outfall, while

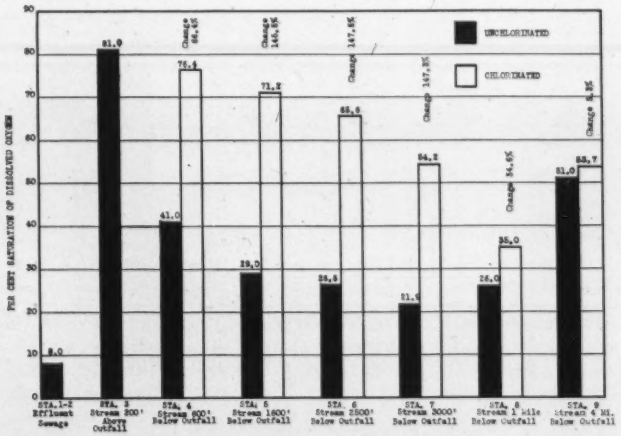

FIG. 2.—The Effect of Sewage Chlorination Upon the Dissolved Oxygen Content of the Receiving Stream.

sometimes saturated, contained on the average 81.0 per cent of its saturation value of oxygen. At stations down-stream the effect of the applied chlorine on the content of dissolved oxygen is clearly demonstrated, the improvement, based on unchlorinated conditions, ranging from a maximum of 147.5 per cent at Station 6, about one-half mile down-stream, to a minimum of 5.3 per cent at Station 9, four miles below the outfall. It is worthy of note that average stream temperatures during periods of chlorination were higher than during non-chlorination, a condition which *in itself* would tend to produce *lower* concentrations of dissolved oxygen in the stream during the periods of chlorination. This effect of improved oxygen conditions is due to two causes: first, the stabilization by chlorine of certain organic constituents of the sewage which normally demand oxygen to support the bacterial life which employs them as food material, and, second, the retardation of this bacterial activity which causes the sewage to travel farther down-stream to regions of greater dilution before active aerobic decomposition takes place. This retarding effect can be detected by comparing the oxygen sag curves for the two conditions represented by the tops of the blocks of Figure 1, although this representation is not drawn to scale horizontally.

Biochemical Oxygen Demand.—In Table VI is presented a summary of the biochemical oxygen demand data for the summer period of 1930. These results are shown in graphical form in Figure 3.

TABLE VI

RECAPITULATION OF BIOCHEMICAL OXYGEN DEMAND RESULTS

Station	Average B. O. D., P. p. m. Unchlorinated	Average B. O. D., P. p. m. Chlorinated	Per Cent Change by Chlorination
1-2	86.70*	52.0*	40.0
3	1.08	...	..
4	23.6	14.0	40.7
5	16.8	6.37	62.0
6	12.2	9.25	24.2
9	3.53	2.95	16.5

Average chlorine dose, 14.2 p. p. m.
Average chlorine residual, 2.2 p. p. m.

* Only results August 19 to August 25 considered. Zero values from B. O. D. of chlorinated sewage September 1 to September 3 considered in error.

In connection with this study an opportunity was afforded to check former findings on the reduction of B. O. D. of settled sewage by chlorination, as represented by the test applied to the effluent immediately before and immediately after the treatment. The results indicate an average reduction from 86.7 p. p. m. to 52.0 p. p. m., or 40.0 per cent, which corroborates nicely the published results of ourselves and other investigators who have studied this phenomenon.

The average 5-day B. O. D. of Bolin Creek above the outfall was only 1.08 p. p. m., indicating a practically unpolluted quality.

At down-stream points the improvement in oxygen demand due to chlorination is striking. The major improvement of 62.0 per cent occurred at Station 5, 1600 feet below the outfall and about one-fourth mile below the point at which the swampy condition of the stream began. Below this station the effect of chlorination on the B. O. D. diminished, but at Station 9, 4 miles and probably several days below, the average improvement amounted to 16.5 per cent.

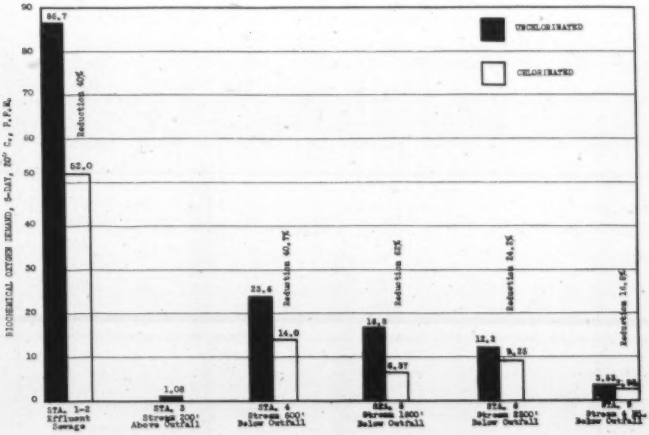

FIG. 3.—The Effect of Sewage Chlorination Upon the Biochemical Oxygen Demand of the Receiving Stream.

Total Bacteria.—Although not pertinent to the original purpose of the investigation, the determination of the bacteriological effects of sewage chlorination on the receiving stream was considered of sufficient interest and significance to warrant the rather laborious additional work of securing this information.

In Table VII and Figure 4 are represented the effect on total 37° C. bacterial count attributable to chlorination which were observed at the various stations from February 13 to April 26, 1930. The average count on the settled sewage was 391,000 per cc., which was reduced to 31,500 by chlorination sufficient to produce an average 10-minute residual of about 0.2 p. p. m., an efficiency of 91.5 per cent. The stream above the outfall

produced on the average 104 colonies per cc. The highest observed efficiency of 96.5 per cent was at Station 5, 1600 feet below the outfall, the lowest, 37.5 per cent at Station 9, four miles below.

TABLE VII

RECAPITULATION OF TOTAL BACTERIA RESULTS

Station	Average Unchlorinated	Average Chlorinated	Per Cent Reduction by Chlorination
1–2	391,000	31,500	91.5
3	104	...	..
4	65,000	6,400	90.3
5	85,000	2,950	96.5
9	1,200	750	37.5

Average chlorine dose, 8.13 p. p. m.
Average chlorine residual, 0.12 p. p. m.

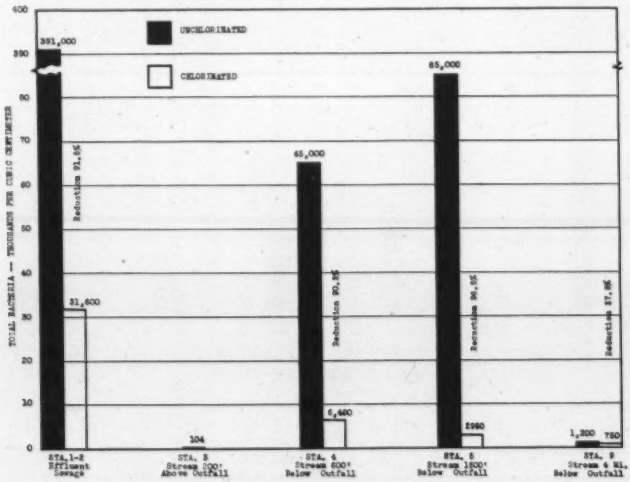

FIG. 4.—The Effect of Sewage Chlorination Upon the Total Bacteria Content of the Receiving Stream.

Bact. Coli.—In Table VIII and Figure 5 are shown the *Bact. Coli* counts in the sewage and stream, and the reduction due to the chlorination of the effluent. Determinations were made in lactose broth incubated for 48 hours at 37° C. with partial confirmation on eosin-methylene blue agar. Results are expressed on the basis of the highest dilutions which showed gas

and confirmed. No adjustments were made on probability considerations. The maximum efficiency of 98.9 per cent was observed at Station 5 on the

TABLE VIII

RECAPITULATION OF *Bact. Coli* RESULTS

Station	Average Unchlorinated	Average Chlorinated	Per Cent Reduction by Chlorination
1–2	40,000	14,750	63.1
3	5	...	..
4	3,450	600	82.6
5	5,400	60	98.9
9	42	3	92.9

Average chlorine dose, 8.13 p. p. m.
Average chlorine residual, 0.12 p. p. m.

stream, while the lowest efficiency, 63.1 per cent, was found with the effluent sewage. This latter result is subject to question, due perhaps to high counts on a few days when the chlorinated sewage contained no

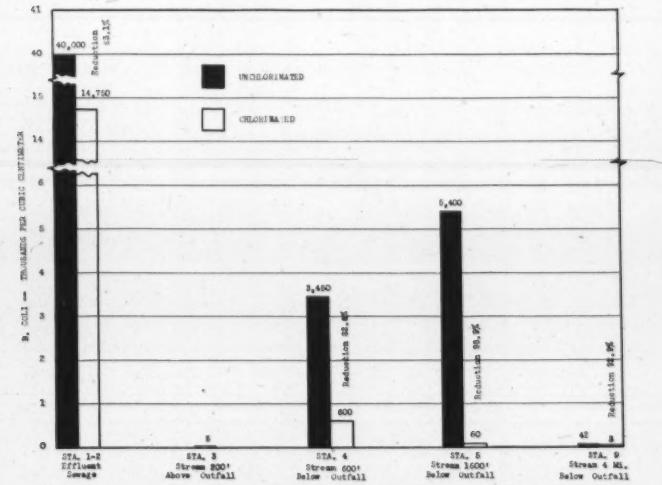

FIG. 5.—The Effect of Sewage Chlorination Upon the Colon Bacilli Content of the Receiving Stream.

residual chlorine. The average *B. coli* content of Bolin Creek above the outfall was 5 per cubic centimeter.

Conclusions

From this study the following conclusions are drawn:

(1) That chlorination of tributary settled sewage produced a remarkable improvement in the physical appearance of the receiving stream.

(2) That this form of treatment is capable of allaying obnoxious odors at treatment works and in the stream receiving the discharge.

(3) That the dissolved oxygen conditions in critical sections of streams may be greatly improved by the application of chlorine to the tributary sewage, due to partial stabilization of non-settleable, organic materials and to retardation of intense bacterial activity. Increase of dissolved oxygen in the stream to the extent of 147 per cent was observed with sewage treated to a residual of 2.0 p. p. m. chlorine.

(4) That efficiencies as high as 25 to 40 per cent biochemical oxygen demand reduction on settled sewage can be attained by chlorination, and that the B. O. D. effects on the receiving stream appear to be commensurate with this stabilization of non-settleable organic material. A B. O. D. reduction as high as 62 per cent was observed with the sewage chlorinated to an average residual of 2.0 p. p. m., at a station on the stream 1600 feet below the sewage effluent outfall.

(5) Chlorination of tributary sewage results in a high degree of bacterial destruction in the receiving stream. Bactericidal efficiencies from 90 to 99 per cent were observed in the case of both total bacteria and *B. coli* which could be ascribed to the chlorine treatment.

Acknowledgments

The authors wish to express their grateful thanks to the Chlorine Institute, who furnished the chlorine and chlorinating equipment for this study, to Mr. L. H. Enslow, Sanitary Engineer of the Institute, who has given invaluable assistance in the planning and prosecution of the work, to the Town of Chapel Hill and its City Manager, Mr. J. M. Foushee, for the use of the sewage treatment plant and for liberal financial assistance in building necessary structures, and to Mrs. Fred Merryfield, who worked day and night to handle, without assistance, all of the bacteriological determinations.

Plant Operation

Chemical-Mechanical Treatment of Sewage and Sewage Sludge at Dearborn

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The City of Dearborn, Michigan, is divided into two sections, East Dearborn and West Dearborn, each of which is sewered as a separate drainage area. East Dearborn, in addition to its own sewage, receives drainage from the Southfield drainage area of the City of Detroit. At the time construction of a new plant was contemplated East Dearborn had an old Imhoff plant with inadequate capacity both for sedimentation and sludge disposal.

The treatment program at Dearborn is quite different from that of most cities. The capacity of the existing East Side Plant was increased and the tanks changed over to plain sedimentation, and a new plant known as the West Side Plant constructed to handle not only West Dearborn sewage but also the sludge from the East Side Plant.

East Side Plant

The East Side Plant is located in the southeast part of Dearborn, along the Rouge River, about three miles north of its confluence with the Detroit River.

The plant consists of a pumping station with a rated capacity of 63 million gallons per day, coarse bar screens, grit chambers, Imhoff tanks and sludge beds. The capacity of the pumping station and grit chambers was adequate, but the tanks had a capacity of only 5.25 million gallons per day, and we had only 20,000 square feet of sludge bed. These capacities were entirely inadequate for the new conditions.

Through studies by means of models our engineers determined that the capacity of the Imhoff tanks could be materially increased by the installation of a new type of inlet which was worked out and designed. Furthermore, it was decided that the sludge could be taken care of by pumping it to the site of the West Side Plant for treatment. Accordingly, in the spring of 1932 the new inlets were built and new sludge withdrawal lines were installed in each of the hoppers. These withdrawal lines were connected with two Fairbanks Morse pumps. The lines were so valved that

sludge could be drawn from any one or more of the twelve hoppers in the tanks. To convey the sludge from the East Side Plant to the site of the West Side Plant, an 8-inch pipe line 20,000 feet in length was constructed by the city, using welfare labor.

The designs for the changes in this plant were prepared by Hubbell, Hartgering and Roth, consulting engineers, and the work was performed by Christman Burke Company at a cost of $32,783. The sludge line was constructed under the direction of Mark B. Owen, Superintendent of Public Works, at a cost of $49,842.

West Side Plant

The West Side Plant is located along the Rouge River approximately three miles upstream from the East Side Plant, on a triangular-shaped piece of land 16 acres in extent. (Figure 1.) Construction was started in August, 1931, and practically completed in March, 1932.

The wet well of the plant is intentionally small so that velocities will be high enough to prevent, in so far as possible, deposition of solids. Sewage

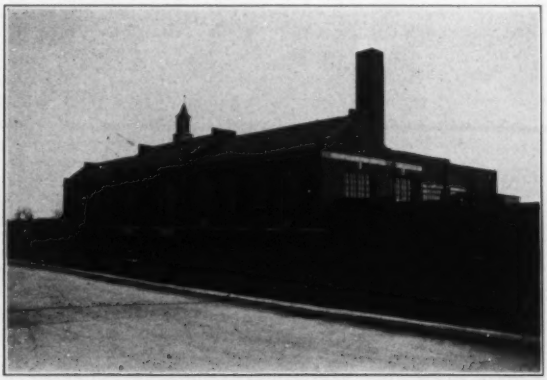

FIG. 1.—Dearborn Sewage Plant.

enters this wet well from a 5 ft. 6 in. concrete intercepting sewer which has a designed capacity of 108 cu. ft. per second.

Screens of a unique traveling type are used ahead of the pumps for the removal of trash. The screen is essentially a belt made up of sections of Everdur bronze bars, each of which is connected on one end to stainless steel cross pins in such a manner that the bars may partially revolve about

the pins. When a section of the screen reaches the top of its travel, a squeegee removes most of the debris to buckets. Completion of the cleaning is effected as the section passes over top center. At this point the bars revolve about the cross pin and strike against a bumper, the jar dislodging any remaining material. The screens have a clear opening of $^3/_4$ inch. They were designed by W. C. Laughlin of Filtration Equipment Corporation.

Four American Well Works vertical centrifugal pumps with capacities of 2, 3, 7 and 12 cu. ft. per sec. discharge sewage through a 20-inch line to the clarifiers for treatment. Two additional pumps, of 30 and 60 c. f. s.

FIG. 2.—Dearborn Sewage Plant. Partial View of Clarifier Showing Effluent Filtered through Laughlin Filter at Periphery.

capacity, provide for storm water pumping. All pumps are equipped for either manual or automatic control. In the discharge line of the sewage pumps is a venturi tube which is connected with a Simplex meter for recording flows.

Two baffled mixing chambers are provided, one for each of two clarifiers, for the purpose of giving uniform dispersion of coagulant throughout the sewage. The inlet end of these chambers is the point where sludge from the East Side Plant is received. Considerable flexibility is available at this point; either East Side sludge, or West Side sewage, or a mixture of the two may be discharged into either or both of the chambers. Mixing the sewage and sludge and applying the resulting composite equally to the two chambers has been the usual practice. Lime and paper pulp in a

water suspension are applied at the inlet end of the mixing chamber. At the outlet end ferric chloride or ferric sulphate is applied, after which the sewage flows through open channels to respective clarifiers.

The clarifiers, of which there are two, are circular, 60 ft. in diameter. Each has a volume of approximately 200,000 gallons. The design capacity of each tank is 4 million gallons per day, and at this rate the displacement time is slightly in excess of one hour. Each clarifier is provided with a Laughlin filter. (Figure 2.) This filter consists of a bed of ground and graded magnetite sand three inches in thickness and eight feet in width, arranged as an annular area within the outer wall of the clarifier. The grading of the sand is such that all will pass a 10-mesh screen and be retained on a 16-mesh. The sand is supported on an Everdur bronze screen, with openings of approximately one millimeter. The theoretical rate on the filter when the clarifier is operating at designed capacity is 2.15 gal. per sq. ft. per minute. However, as the effective area of the filter is less than the actual area, this rate in actual operation becomes approximately 3.0 gal. per sq. ft. per minute. The sewage flow through the clarifier is radial; the sewage enters at the center, flows outward beneath a circular baffle, and passes upward through the filter, then spills over weirs into an effluent channel. From this channel it discharges into an underground conduit which is baffled in such a manner as to give a short contact period for chlorination. When used, chlorine is applied by a Wallace and Tiernan vacuum type chlorinator.

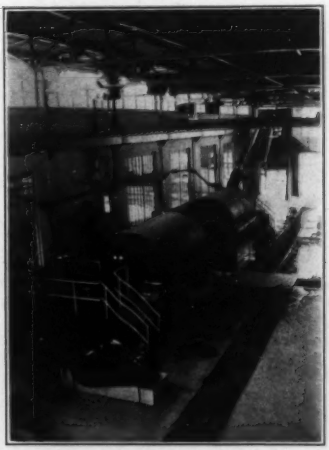

FIG. 3.—Dearborn Sewage Plant. Vacuum Filters for Dewatering Sludge.

The mechanism for cleaning the sand in the filters is unique and effective. It consists essentially of a solenoid traversing the filter at the rate of 4 ft. per minute. A timed relay switch alternately closes and opens the energizing electrical circuit 18 times per minute. When the relay closes the solenoid picks up a section of the sand entirely clear of the supporting screen, and when the circuit opens drops it back into place. This operation gives an effective scrubbing action. At the same time, due to a main-

tained difference in head, settled water from below the filter passes up through the sand in the magnet and carries with it the dirt that has been scrubbed loose from the sand. This wash water is collected in a box or tank that is hung on the rearward side of the solenoid and is returned to the center of the clarifier by a small centrifugal pump. The bottom of this box serves as a trowel to smooth off the sand that has been agitated by the magnet. Thus the washing of the filters is continuous, and a sample of washed sand picked up at any time will show that it has been thoroughly cleaned.

Sludge is removed from the clarifiers by a Dorr mechanism so designed that it carries the filter cleaning apparatus. The collected sludge flows by gravity to two sumps, one of which is provided for each clarifier. In

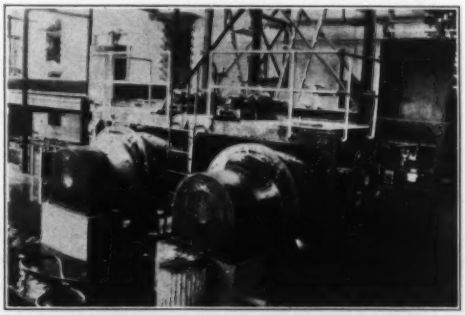

FIG. 4.—Dearborn Sewage Plant. Pebble Mills for Grinding Paper and Lime.

the sumps the sludge is conditioned for filtering, and is then pumped to two 8 by 12 ft. Oliver filters. (Figure 3.) These filters are usually operated with approximately one-third of the area submerged, and at a speed of one revolution in slightly less than two minutes. The cake produced is discharged onto a belt conveyor which carries it to two storage hoppers. At the present time, the sludge cake is disposed of by dumping it on land adjacent to the plant. We have hopes of obtaining an incinerator in the future for burning the sludge.

Two pebble mills are used for preparing lime and paper for application to the sewage. (Figure 4.) These mills, which are rotating steel cylinders 4 ft. in diameter and 6 ft. long, containing several bushels of aggregate, grind the paper to a coarse pulp and put the lime into solution. They are fed by conveyors. Control of the quantities of lime and paper fed to the

sewage is determined by dumping weighed batches of the materials into the mills at uniform intervals of time, usually five minutes. One mill, by means of separate connections, is used for supplying lime to the sludge sumps for conditioning. Adjacent to the pebble mills is a series of storage bins which are loaded from a truck runway that is built over them. Ferric chloride, for sewage coagulation, is stored on the same runway in a 750-gallon rubber-lined tank. From this tank a 2-inch rubber hose conveys the liquid ferric chloride to two calibrated orifices, one of which is provided for each mixing chamber, and which control the quantity of ferric chloride fed. The rate of feed through the orifices is controlled by changing their elevation with respect to a constant-head chamber that feeds both. Ferric chloride used as a filter aid in conditioning sludge is applied by dumping it directly from carboys into the sludge sumps. When ferric sulphate is used for coagulation, it is fed by means of a revolving table type dry-feed machine with an associated solution tank, and a proportioning pump for water supply.

The entire plant is housed in a single building of Early American architecture 160 ft. by 180 ft. in plan. The building is divided into three sections: the front section contains the office, laboratory, motor room, electrical service rooms, boiler room, locker rooms and the like. The vacuum filters, pebble mills and appurtenant equipment are located in the mid-section of the building, while the rear section houses the clarifiers, mixing chambers and sludge pumps.

The plant was constructed under three contracts. The general contract included all concrete work in the pump well, clarifiers, building and roadways. It also covered the superstructure, heating, lighting and ventilating of the same, outside grading and miscellaneous items.

The pump contract covered furnishing and installation of sewage pumps and motors, together with the appurtenant electrical equipment, and the venturi meter.

All necessary equipment items, such as traveling screens, clarifier mechanisms, Laughlin filters, pebble mills, Oliver filters, conveyors, miscellaneous pumps, etc., were furnished and installed under the equipment contract by the Filtration Equipment Corporation of New York.

Hubbell, Hartgering and Roth, Consulting Engineers, Detroit, prepared the designs for the work carried out under the general and pumping station contracts. The process and equipment plans were by W. C. Laughlin of the Filtration Equipment Corporation of New York. Design and construction were supervised by Mark B. Owen, Superintendent of the Department of Public Works and Engineering, Dearborn.

The costs were as follows:

General Contract	$242,000.17
Pump Contract	46,561.06

Equipment Contract	167,613.67
Engineering, Inspection, Etc.	22,678.08
Total	$478,852.98

This represents, excluding the pumping station, a cost of $54,036 per million gallons of treatment capacity.

Plant Loadings

The East Side Plant receives sewage from East Dearborn and Detroit as well as from the Ford Motor Company, which is located within Dearborn. East Dearborn has an area of 3700 acres and a present estimated population of about 40,000 people. The Detroit sewage, which is handled by Dearborn by agreement with Detroit, comes from an area of 22,400 acres with a population of about 95,000. The estimated equivalent population of the Ford Motor Company is 18,000. This makes a total contributing population of 153,000. The average daily flow is about 18 million gallons. Our engineers estimate that in 1945 the population connected with this plant will be 355,000 and the flow will be 68 million gallons per day.

The West Side Plant receives sewage from West Dearborn, which has an area of 6820 acres and an estimated population of about 12,000. The daily flow is 2.85 million gallons. The 1945 estimate is a population of 35,000 people contributing 4 million gallons per day. By far the greater load that is applied to the West Side Plant is the sludge pumped from the East Side plant, from a population of 153,000. In 1945 the plant will give direct sewage treatment facilities only to 35,000 people, but it will also be treating East Side sludge from a total of 390,000 people.

Operation and Results

The operation of the plant can logically be divided into two periods: the first from May to September, inclusive, 1932, and the second from October, 1932, to February, 1933, inclusive. During the first period, the sewage flow averaged less than one million gallons per day, while the flow of sludge from the East Side Plant was approximately 400,000 gallons per day. That is, relatively speaking, the sewage flow was very low and the sludge flow was quite high. In the second period the reverse was true. The sewage flow averaged 2.85 million gallons per day, whereas the sludge flow amounted to 250,000 gallons per day. The combined flow of sewage and sludge is now 3.1 million gallons per day. As this is handled in 16 hours the rate of operation becomes 4.7 million gallons per day, which is equivalent to 60 per cent of the design capacity of the plant (8.0 million gallons per day).

When the plant was first put into operation and until July, 1932, it

was run on a 24-hour schedule. During July, and ever since, it has been run only 16 hours per day in the interest of economy. Sewage is pumped from 8 o'clock in the morning until midnight. During the midnight to the 8 A.M. period the sewage is allowed to store in the interceptor. Obviously, sedimentation takes place in the interceptor so that when pumping is started in the morning, relatively clear and extremely weak supernatant, one might call it, is drawn from the interceptor. Later in the day, when the elevation of water in the interceptor is lower and velocities begin to increase, some of the solids that have been deposited in the sewer are picked up, and increase materially the strength of the sewage. In order to balance our load in so far as possible, it is our present practice to pump sludge from the East Side Plant during the period of extremely weak sewage at the West Side Plant. This is accomplished by pumping sludge from 8 A.M. to 4 P.M. As one would expect, the sludge is somewhat stronger than that received when we were pumping 16 to 24 hours a day, but when it is diluted by the weak sewage, it can be handled quite readily. During the first period of operation, the suspended solids in the West Side sewage averaged 335 p. p. m. and the East Side sludge 5370. The mixing of these two gave an applied composite averaging 1545 parts per million; the effluent contained only 34 p. p. m. suspended solids. This is a reduction of 97.9 per cent. During this same period the B. O. D. of the West Side sewage was 136, the East Side sludge 1200 and the composite 333. The effluent contained 41 p. p. m., the reduction amounting to 87.5 per cent.

Inasmuch as the raw materials to be treated are so radically different from those received at the average sewage plant, the quantities of chemicals used, to achieve the degree of treatment illustrated by the above figures, have been set up on the basis not only of pounds per million gallons, but also as pounds per pound of suspended solids removed, and pounds per pound of B. O. D. reduction. The following table gives these figures:

Chemical	Pounds per Million Gallons	Pounds per Pound Suspended Solids Removal	Pounds per Pound B. O. D. Removal
Calcium Oxide	1170	0.090	0.48
Ferric Chloride	342	0.026	0.14
Paper	368	0.028	0.15

In September, 1932, additional sewers were connected to our interceptor with the result that the sewage flow at the West Side Plant increased materially. At the same time the strength of the sewage decreased. Apparently this was caused by excessive infiltration of ground water in a section of the intercepting sewer that was constructed in bad soil. The theoretical amount of ground water we should receive is 950,000 gallons per day, but presumably the actual quantity that we receive is more than double that amount. This fact will account for the lower suspended

solids and B. O. D. content of the West Side sewage during the second period of operation. During this period the suspended solids in the West Side sewage averaged 195 p. p. m. and East Side sludge contained 6240 p. p. m., which gave us a composite of 645 p. p. m. The effluent contained 32 p. p. m. giving a suspended solids reduction of 95.2 per cent. The B. O. D. of the West Side sewage was only 40 p. p. m. while the East Side sludge ran 1650. The composite, as applied to the process, carried 130 p. p. m. We produced an effluent averaging only 16 p. p. m. B. O. D. This accounts for a reduction of 87.8 per cent.

Due primarily to the fact that better control of coagulation was exercised during this period, materially less chemicals were used to effect the clarification and purification which the above figures indicate. The quantities are tabulated in the same manner as were those used during the first period. During January and February, ferric sulphate was used as a coagulant in place of ferric chloride. This is indicated in the tabulation.

Chemical	Pounds per Million Gallons	Pounds per Pound Suspended Solids Removal	Pounds per Pound B. O. D. Reduction
Calcium Oxide	261	0.051	0.27
Ferric Chloride	146	0.023	0.12
Ferric Sulphate	173	0.049	0.18
Paper	242	0.044	0.23

The volume of sludge handled on the Oliver filters has been quite large, due primarily, of course, to the sludge received from the East Side Plant. During the first period of operation the wet sludge amounted to 13,000 gallons per million gallons of flow treated. In the second period the quantity per million gallons treated dropped to 6300 gallons.

There have been two distinct and different periods in the operation of the vacuum filters for dewatering the sludge. The latter periods are not, however, quite coincident with the former. The first sludge filtering operation period extended from May to October, 1932, inclusive, during which time lime alone was used as a filter aid. The quantity of lime used was 150 pounds per thousand gallons of sludge. We were able to obtain an average rate of only 4.3 pounds of dry solids per square foot of filter area per hour, but the moisture content of the sludge cake produced was only 56.7. This is an unusually low moisture content for sludge dewatered on vacuum filters.

In November, 1932, ferric chloride was used as an additional filter aid, and at the same time a number of changes were made in the filters. Immediately a much higher rate of production was obtained. The filters were speeded up to such an extent that the drums were making a revolution in less than two minutes, whereas formerly a revolution in from five to six minutes was considered good. From November, 1932, to date, the rate has averaged 7.5 pounds of dry solids per sq. ft. per hour.

There has been some increase in the moisture content of the cake, but even so, the average for the period was only 62 per cent, and the maximum month average 63 per cent. To accomplish this 130 pounds of calcium oxide and 31 pounds of ferric chloride were used per thousand gallons of sludge.

This increased production rate has resulted in a decrease in power and labor costs. The actual quantity of sludge handled per day averaged about the same during both periods of filter operation. To dewater this quantity of sludge requires, with the present operating schedule, an average of ten filter hours five days a week. When lime alone was used, and before the filter alterations, it required thirteen hours a day seven days a week to accomplish the filtration, or on the five-day week basis it would have required eighteen filter hours per day. The filters now turn out approximately 6 tons of sludge cake per hour which corresponds to $2^1/_4$ tons of dry solids per hour.

The removal of suspended solids by the Laughlin magnetite filters was checked over a period of two months. The results showed that during the test period sedimentation accounted for a reduction of suspended solids amounting to 71.4 per cent. The filters removed an additional 24.6 per cent, giving an over-all reduction of 96 per cent. The filters really removed larger quantities of material than these figures would indicate as the applied liquor contained in addition to 28.6 per cent of the original suspended solids appreciable amounts of finely divided floc. Thus, if we compare the applied water directly with the filtrate the removal by the filter becomes 86.3 per cent.

The West Side Plant is manned by a relatively small force, only six being used for actual operation under present conditions. They are a chief operator, three operators and two assistant operators. In addition to these there is a truck driver and a janitor. In the laboratory two men make all the analytical determinations, both routine and those necessary in connection with experimental work, for both sewage plants, and keep records of operation. They also test materials used by the city. The East Side Plant has as its force a chief operator and three operators. Both plants are under the direct supervision of the writer.

The results obtained at Dearborn's new treatment plant give sufficient evidence that this type of treatment has a definite place among the various schemes of sewage treatment in use today. It provides a degree of treatment that is far in excess of that provided by plain sedimentation. In fact, it is sufficiently high to approach that of the activated-sludge process or trickling-filter installations, although it is still somewhat below them.

Economically, also, it fits into a similar place. As shown by the figures quoted for the construction cost of Dearborn's plant, we believe that the

cost was very little in excess of the cost of a plain sedimentation plant of similar capacity. Furthermore, although the costs of operation at Dearborn are not comparable with those at places treating only sewage, they convince us that the operation costs would lie between those of plain sedimentation and activated-sludge treatment.

The Laughlin Process of Sewage Treatment

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General Description of Process

The Laughlin process of sewage treatment consists of precipitation of suspended, colloidal and some dissolved matter from raw sewage by use of chemicals and paper, and the application of mechanical devices to effect flocculation and a more efficient and more rapid separation of flocculated solids than can be accomplished in clarification by sedimentation alone. Additional treatment is obtained by chlorination of the clarified effluent. Sludge produced is suitable for handling by mechanical means, consisting of dewatering continuously on vacuum filters and disposal by incineration or on waste land.

Prior to addition of chemicals or treatment, the larger floating solids are removed by means of Laughlin traveling bar screens having bars with $^1/_2$- to 1-inch clear openings. Paper, lime and ferric chloride are added and thoroughly mixed with the sewage either in baffled mixing boxes or chambers equipped with stirring devices. The chemically treated sewage may go directly to the Laughlin clarifier or to flocculators preceding the clarifiers. It has been recently demonstrated by laboratory tests that economies in the use of chemicals are possible and a better floc produced by flocculation for 20 to 30 minutes in tanks equipped with slow stirring devices. In the case of a stale or septic sewage it is desirable to flocculate by means of diffused air or to aerate for a short period preceding paddle flocculators.

The Laughlin clarifier consists of a tank equipped with a mechanical device for moving sludge to a sump, a filter consisting of a 2- to 3-inch layer of crushed magnetite occupying about 50 per cent of the tank surface, and a magnetic device which cleans the magnetite by lifting up a portion at a time and washing it as it is released through the upward flowing sewage, a pump for returning the dirty wash water to the influent of the tank, and traction type of drive for operating the sludge mechanism and the magnetic cleaner. The Laughlin equipment is suitable for installation either in rectangular or circular tanks.

Chemically treated or flocculated sewage is introduced into the clarifier at a rate permitting the larger solids to settle quite rapidly. The liquor, which still contains some very finely divided floc, flows upward and filters through the magnetite sand. The filter retains floc which would normally require excessively long retention for sedimentation.

The effluent may be discharged to a receiving body of water direct from

the clarifier or may be given further treatment with chlorine. Chlorination not only results in sterilization, but accomplishes a further reduction amounting to about 25 per cent of the B. O. D. of the unchlorinated effluent.

The sludge drawn from the bottom of the clarifier is conditioned further with either lime or ferric chloride or both, dewatered on vacuum filters and discharged to a belt conveyor, where it may go either into an incinerator or onto trucks to be carted away for disposal on waste land. If an incinerator is used it may be possible to recover some of the lime from the ash, to be re-used in the process.

Commercial waste paper is ground into a coarse pulp by means of a ball mill, or shredder, mixed with water and slaked lime and added to the sewage in the form of a slurry. Slaking of lime may be carried out in a screw conveyor, separate tank, commercial slaker or in a properly designed ball mill. Ferric chloride solution is added to the sewage after the other conditioners. Ferric sulphate may have its application as a substitute for the chloride, depending on local conditions. Experiments are now under way at Dearborn on the use of ferric sulphate.

Normally the liquid ferric chloride containing 40 per cent $FeCl_3$ is the cheaper, but for small plants and long freight hauls the solid material containing 60 per cent $FeCl_3$ may be more adaptable. This would require additional equipment for dissolving the crystals.

Development of Process

This process was developed by Mr. W. C. Laughlin, Filtration Equipment Corporation, 350 Madison Avenue, New York. The development was started in an endeavor to find a method of sewage treatment, by other than biologic means, that would produce a well clarified effluent, which after chlorination might be suitable for discharge into a receiving body of water, where conditions do not warrant an oxidized or nitrified effluent.

Preliminary experimentation consisted of numerous small-scale tests in New York on precipitation of sewage solids with coagulants, aided by finely divided fibrous material and final clarification by upward filtration through sand. This was first tried on a working scale in coöperation with the City of Dearborn in a testing station handling 250,000 to 500,000 gallons per day. The testing station was operated for about 10 weeks using ferric chloride, lime and paper pulp. Because of the tendency for the sewage to break through the sand at high rates of flow in prior tests, crushed magnetite, being heavier, was used at Dearborn as a filter medium. This was placed in removable trays which could be backwashed or cleaned, as clogging occurred. The need for a continuous type of cleaning mechanism became apparent. Mr. Laughlin thereupon developed a solenoid type of magnetic cleaner for washing the magnetite. Several months were spent

in the laboratories of Columbia University proving the principles and perfecting the mechanism of a magnetic cleaner. The Coney Island experimental unit was then built to demonstrate the practical application of this device.

The Dearborn West Side Plant was built on the basis of results obtained from the various experiments and tests. It was designed and constructed under the supervision of Mark B. Owen, Supt. of Public Works, Dearborn, with Hubbell, Hartgering and Roth of Detroit as consulting engineers. The plant has been in operation for over a year handling the West Side sewage, and sludge from the East Side Plant. The routine has been varied from time to time to determine the most suitable operation for the Dearborn conditions. These are considerably complicated by the sludge from the East Side Plant, and the problem as a whole at the West Side Plant (Laughlin process) more nearly approaches one of mechanical handling of sludge than of sewage treatment, although there are several periods during the year when sewage alone was treated in one of the clarifiers. Numerous tests in the plant laboratory on the use and application of chemicals to both sewage and sludge have led the way to the many improvements in plant operation and have demonstrated the possibilities of further economies.

In the meantime tests were also conducted at Coney Island on typical domestic sewage in a testing station handling about 12 to 14 thousand gallons per day. The data obtained at Coney Island and at Dearborn on raw sewage alone serve as a basis for determining what may be expected from this process on normal sewage. A special two weeks' test was conducted at the Coney Island Testing Station by Mr. E. Hurwitz, Sanitary Chemist, Chicago, and the writer.

Observation of operation at Dearborn and Coney Island have demonstrated the need of proper application of chemicals and paper and thorough mixing with the sewage to form a floc. It is now concluded from the extensive laboratory tests that proper flocculation prior to precipitation and settling in the clarifiers is of considerable value both in the savings of chemicals and efficiency of operation.

Description of Laughlin Testing Stations and Plant

Dearborn Testing Station (1).—The testing station at Dearborn consisted of a wooden tank 30 ft. long, 12 ft. wide and 12 ft. deep equipped with an upward-flow type filter. Raw sewage pumped with a Jennings self-priming pump was treated in the clarifiers with a detention period of $1^1/_2$ to 3 hours. Milk of lime and paper pulp were mixed in two small wooden tanks before addition to the sewage. Ferric chloride solution was added to the influent end of the clarifiers. The effluent was chlorinated with a Paradon machine. A hammer mill was used to break up the paper. Sludge was dewatered with a small rotary vacuum filter.

Dearborn West Side Plant (2).—Sewage and sludge is treated by the Laughlin process at the West Side Plant. This plant consists of a laboratory, pumping station, mechanically cleaned Laughlin traveling screens, storage for chemicals and paper, ball mills for breaking up paper, chemical feeding apparatus, mixing channels for introducing paper, lime and iron solution into the sewage, Laughlin clarifiers including magnetite filter and magnetic cleaner, chlorinators, sludge sumps, Oliver vacuum filters and sludge conveyors.

The pumping station has capacity for handling the dry weather and storm flow. Two pumps, 90 c. f. s. total capacity, discharge directly into

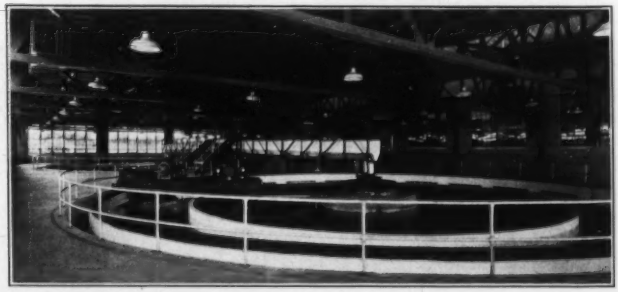

FIG. 1.—Dearborn West Side Plant. 60-Foot Diameter Laughlin Clarifier Showing Overhead Influent Trough, Magnetite Filter and Cleaner and Sedimentation Portion.

the river. Pumps discharging through the plant have a capacity of 24 c. f. s.

The screens have $^3/_4$-inch clear openings. Screenings are broken up in the ball mills and returned to the raw sewage.

Commercial waste paper and lime is fed to the ball mills at $2^1/_2$-minute intervals from a flight conveyor carrying properly proportioned amounts of each. Sufficient water is added to the ball mills to produce a slurry consisting of lime and paper pulp. The slurry is discharged into a sump from which it is pumped into the sewage-lime-paper mixing box. A screw conveyor is also available for feeding lime. Both Prestolite lime containing 50 per cent moisture and 35 per cent calcium oxide, and quicklime of 95 per cent calcium oxide content have been used in the process. The Prestolite available at low cost locally from a carbide plant has been used more than the quicklime, although the lime of higher calcium content is somewhat more effective as a precipitant.

Iron solution is added at the effluent end of the sewage-lime-paper mixing

box. A generator is available for making ferric chloride. It has, however, been more practical to use commercial ferric chloride. Ferric sulphate has also been tried, but its satisfactory application is dependent on the development of a proper device for dissolving and feeding the solution. This is under way at the present time.

The Laughlin clarifiers are 60 ft. in diameter and 12 ft. deep, each having a capacity of 172,000 gallons (Figure 1). They are equipped with a magnetite sand filter bed 8 ft. wide around the periphery, and Dorr type traction sludge conveyor mechanism also carrying the Laughlin magnetic cleaner. Sewage is added from an overhead trough and drops about 6 ft. into a central well. The effluent which is discharged to the river is chlorinated with a Wallace and Tiernan machine when required. Sludge is drawn into a 3000-gal. capacity sump, of which there are two, where either lime or lime and ferric chloride are added, before dewatering on Oliver vacuum filters.

FIG. 2.—Dearborn Plant—Oliver Vacuum Filter. Sludge Cake as Discharged from Sludge Storage Hopper Used for Loading Trucks.

There are two vacuum filters 8 ft. in diameter and 12 ft. face each. Sludge cake is discharged onto a belt conveyor feeding an overhead hopper and taken away and dumped by trucks (Figure 2).

Coney Island Testing Station (3).—The Coney Island testing station is located in sewage Pumping Station No. 3 of the Department of Sanitation, Brighton Beach, Coney Island, New York. Sewage is pumped from the suction well following the bar screens to a baffled chemical mixing chamber, having about an 8-minute detention period. A pre-prepared mixture of lime and paper is fed in paste form by means of small flight conveyor into the inlet of this chamber where it is thoroughly mixed with the sewage by means of a motor driven propeller. Ferric chloride or sulphate solution is added at the outlet end of the mixing chamber. The chemically dosed sewage then flows into the Laughlin clarifier which is equipped with a magnetite filter, magnetic cleaner and sludge conveying apparatus (Figure 3). The clarifier is 6 ft. in diameter, has a side depth of 3 ft. 5 in. and a bottom sloping to a central sump. The bottom of the sump is about 5 ft. from the water surface. The capacity of the tank is 90 cu. ft. and the filter area is 11.15 sq. ft. The filtered effluent after chlorination

with a Wallace and Tiernan chlorinator is discharged through a steel barrel having a detention period of about 5 minutes, and finally measured over a

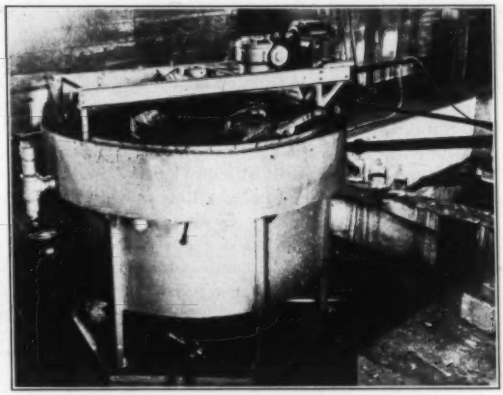

FIG. 3.—Coney Island Testing Station—Laughlin Clarifier and Magnetic Cleaner.

V-notch weir. A 1-ft. diameter by 1-ft. face Oliver vacuum filter is used for sludge dewatering tests.

Operation and Results of Laughlin Process

Data and results of operation of the Laughlin process are available on (1) experiments conducted at the Dearborn testing station during a period of 10 weeks, (2) operation of the Dearborn Sewage Treatment Works from May, 1932, to February, 1933, inclusive, and (3) experiments carried out in a test plant at Coney Island, N. Y., from Aug. 29 to Sept. 16, 1932.

The sewage treated at the Dearborn testing station represented 1 per cent of the dry weather flow from a population of approximately 146,000 people. The testing station was operated 24 hours per day. Standard A. P. H. A. analyses were made on a daily composite of samples collected hourly.

The Coney Island testing station was operated 24 hours per day on a schedule of two 12-hour shifts, treating sewage from the heart of the Coney Island amusement center (at the height of the season) from an otherwise purely domestic area. A large number of salt water baths contribute to the flow discharged through Pumping Station No. 3 thereby increasing the dissolved total solids content of the sewage. Samples of raw sewage, unchlorinated and chlorinated effluent, respectively, were taken every half

hour and composited each 12 hours for analysis. Chemical analyses were made according to A. P. H. A. Standards. Chlorine in samples taken for dissolved oxygen determination were neutralized as recommended by Thierault in the U. S. Public Health Reports Supplement No. 90. Residual chlorine and alkalinity of samples for biochemical oxygen demand tests were neutralized and seeded with settled raw sewage. An effluent having a pH of about 10.0 was maintained throughout the test. Caustic alkalinity was present only on 3 days. Table I shows the operation and analytical data for each shift during the special test.

The West Side Plant treats the raw sewage from the west side of Dearborn and sludge pumped from the East Side Plant. The East Side sludge is composed of solids from a flow of about 15 m. g. d. settled in modified Imhoff tanks with the hoppers used only to provide temporary storage. This sludge often remains in the bottom of the tanks for several days before being pumped to the West Side Plant and is frequently in a semi-septic condition. It is also difficult to draw sludge of uniform concentration from the hoppers. The West Side sewage is very dilute and has amounted to flows of 1.0 to 3.5 m. g. d. The estimated population is 12,000 tributary to the West Side and about 145,000 to the East Side Plant. Although normal operation consists of treating mixtures of East Side sludge and West Side sewage in the Laughlin clarifiers, they have also been treated separately.

Operation of the Dearborn West Side Plant was started about the middle of March, 1932. Due to the preliminary adjustment period an uninterrupted record of data and results did not start until May 1, 1932. Although the plant has operated continuously to date, there have been changes in routine. Until July 1, 1932, the plant was operated 24 hours per day. Since then sewage has been stored in the interceptor from 12 midnight to 8 A.M. and the daily sewage treated during 16 hours. This method of operation caused the concentration of the sewage to fluctuate during the day, starting with a weak sewage in the morning and increasing in strength as the interceptor was drawn down. Experience indicates that for practical purposes best results are obtained when chemicals can be proportioned according to flow and concentration. As no means of making rapid adjustments in the chemicals applied were provided, the plant was operated on the basis of a fixed dose of chemicals, which at times resulted either in overdosing the weaker sewage or underdosing the sewage of higher concentration. At first only one Laughlin clarifier at a time was used for treating the mixture of East Side sludge and West Side sewage. About the end of September, 1932, another sewer was connected to the West Side Plant, providing sufficient sewage to operate two clarifiers in parallel on mixtures of sewage and sludge equally divided.

There were about 48 days during May, June and July, 1932, when one

TABLE I

DATA ON OPERATION AND ANALYSES, LAUGHLIN PROCESS OF SEWAGE TREATMENT, CONEY ISLAND, N. Y.

Date, 1932		Rate of Flow, Gal. per 12 Hr.	Based on Rate of Flow: Detention Period Hr.	Filtering, Gal. per Sq. Ft. per Minute	Chemicals, Pounds per M. g. Sewage Treated: Paper	Lime as CaO	Ferric Chloride	Chlorine**	Suspended Solids: Inf.	Effluent Unchl.	Chlor.	5-Day B. O. D.: Inf.	Effluent Unchl.	Chlor.
8/30–31	Day	9380	0.86	1.17	260	615	55*	55	312	25	3	240	49	33
	Night	8000	1.00	1.00	358	840	140*	75	54	26	10	92	48	29
8/31–9/1	Day	9150	0.88	1.14	250	586	128*	61	160	13	22	135	43	34
	Night	9380	0.86	1.17	294	684	122*	54	117	33	12	85	52	12
9/1–2	Day	7400	1.09	0.92	275	648	107*	49	238	20	8	140	28	15
	Night	8770	0.92	1.08	337	785	113	52	162	22	13	55	23	19
9/2–3	Day	7430	1.08	0.92	320	750	144	56	120	34	10	250	42	26
	Night	5050	1.59	0.63	257	602	110	69	48	18	4	102	24	26
9/3–4	Day	5090	1.59	0.63	519	1200	170	73	146	26	12	170	36	45
	Night	4460	1.80	0.56	486	1130	190	69	70	17	9	75	17	33
9/4–5	Day	5300	1.52	0.66	480	1100	184	65	216	30	10	130	44	26
	Night	8320	0.97	1.03	320	720	132	55	84	24	7	130	42	25
9/5–6	Day	5100	1.58	0.63	572	1330	108	55	120	16	10	75	31	19
	Night	7500	1.07	0.93	270	630	110	41	130	6	11	57	29	18
9/7–8	Day	6560	1.23	0.82	455	1060	201	71	132	23	13	160	31	25
	Night	5330	1.51	0.66	500	1170	231	71	50	5	11	48	30	13
9/8–9	Day	6500	1.24	0.81	495	1150	248	54	171	29	17	215	44	32
	Night	6700	1.20	0.83	341	798	223	72	70	15	7	112	58	25
9/9–10	Day	6700	1.20	0.83	443	1030	208	75	134	16	8	210	62	56
	Night	6790	1.18	0.84	392	912	205	61	72	14	6	135	52	40
9/10–11	Day	7600	1.06	0.95	548	1280	195*	57	138	33	18	180	68	36
	Night	7060	1.14	0.88	326	766	226*		61	11		120	62	
Avg.	Day	6930	1.16	0.86	420	980	159	61	181	24	12	173	43	31
	Night	7020	1.14	0.87	350	820	164	62	84	17	9	92	40	24
	Combined	6975	1.15	0.87	385	900	161	62	132	21	10	132	41	28
Per Cent Removal	Day									87	93		75	82
	Night									80	89		57	74
	Combined									84	92		69	79

* Ferric sulphate figured to chloride

** Chlorine based on rate of flow

clarifier was operated on raw sewage alone. In this group there were days when the suspended solids in the sewage were exceptionally high and other days when the lime dosage was excessive. The results of 26 days believed to be more nearly representative of normal sewage with the proper lime dosage are shown in Table II. In November and December, 1932, the

TABLE II

LAUGHLIN PROCESS OF SEWAGE TREATMENT OPERATION ON RAW SEWAGE AT DEARBORN

Date, 1932	Rate of Flow, M. g. d.	Chemicals Used, Lb. per M. g. Lime as CaO		Suspended Solids Inf., P.p.m.	Eff., P.p.m.	% Removed	% Vol. Inf.	% Vol. Eff.	5-Day B. O. D. Inf., P.p.m.	5-Day B. O. D. Eff.,* P.p.m.	5-Day B. O. D. % Removed
		Paper	$FeCl_3$								
May 21	1.00	318	600	330	550	21	96	54	95	142	53	63
June 11	1.17	330	230	316	63	23	64	97	87	44	20	59
13	0.68	458	392	367	190	22	88	65	91	51	35	31
14	0.89	374	486	236	123	20	84	58	85	80	34	58
15	0.96	202	364	213	141	18	87	67	72	82	37	55
16	1.05	258	224	175	97	15	85	91	93	76	31	59
19	0.75	396	254	322	463	22	95	56	91	235	20	92
21	0.77	520	242	276	320	28	91	50	97	125	72	42
22	0.99	310	191	515	131	16	88	78	50	96	32	67
23	0.99	310	234	250	80	14	83	91	71	97	30	69
24	0.91	316	480	157	110	20	82	70	90	86	42	51
25	0.78	362	204	183	184	29	84	39	90	82	40	51
27	1.06	179	172	226	284	14	95	54	93	155	41	74
28	1.06	270	177	236	141	13	91	55	85	92	41	55
29	1.05	280	174	229	124	14	89	60	71	87	39	55
30	1.06	285	118	226	118	16	86	67	94	74	38	49
July 1	2.20	330	219	163	329	22	93	47	91	99	38	62
2	2.13	410	212	194	81	21	74	67	90	77	39	49
4	1.39	310	21	178	57	8	86	72	75	46	15	67
6	1.18	230	178	193	203	23	89	55	74	110	39	66
8	1.26	202	186	183	413	21	95	43	71	112	26	77
9	1.17	87	231	195	513	19	97	48	74	240	40	83
10	0.99	0	0	12	84	7	92	84	85	69	22	68
16	1.26	222	237	331	153	14	91	33	36	73	43	41
18	1.17	231	424	171	496	41	92	67	78	375	76	80
19	1.02	216	123	230	78	31	60	90	87	95	44	54
Av.	1.11	285	245	235	212	20	91	65	80	112	38	66

* Unchlorinated effluent.

routine operation was changed again. One clarifier was operated at a rate equal to design capacity on West Side raw sewage. Owing to a very dilute sewage, a satisfactory effluent was obtained practically without chemicals or paper. These results are shown in Table III. The East Side sludge was handled separately in the other clarifier, which effected considerable concentration of the sludge and a well clarified supernatant discharged through the Laughlin filter. The sludge received from the East Side Plant

amounted to 200,000 to 400,000 gallons per day and contained 0.75 per cent dry solids. The detention period was from 10 to 20 hours.

A summary by months from May to October, 1932, inclusive, and January and February of 1933, showing the operating, analytical data and per cent removal for the Laughlin process at Dearborn handling a mixture of

TABLE III

OPERATING DATA, LAUGHLIN CLARIFIERS AT DEARBORN WITHOUT USE OF CHEMICALS

Description	1932 November			December		
M. G. D., Treated (16 Hrs.)	2.75			2.95		
M. G. D. Rate (24-Hr. Basis)	4.10			4.43		
Detention Period, Hrs.	1.00			0.93		
Filtering Rate, Gal./Sq. Ft./Min.	2.20			2.56		
Settling Rate, Gal./Sq. Ft./24 Hr.	2840			3070		
	Inf., P. p. m.	Eff., P. p. m.	% Removed	Inf., P. p. m.	Eff., P. p. m.	% Removed
Total Solids	746	710	5	775	637	18
Per Cent Volatile	43	46		44	46	
Suspended Solids	69	26	62	190	28	85
Per Cent Volatile	40	50		33	50	
Chloride	19	23		17	20	
Alkalinity	254	244		242	234	
pH	7.7	7.8		7.6	7.7	
Dissolved Oxygen		6.5			7.3	
5-Day B. O. D.	21	13	38	31	13	58

East Side sludge and West Side sewage is compiled in Table IV. Average analyses of East Side sludge and West Side sewage composing the mixture handled in the Laughlin clarifiers is shown in Table V. Owing to the fact that the sewage has been considerably weaker since November, the averages are divided into two periods.

The principal coagulants used were ferric chloride, Prestolite lime and paper, but quicklime (90 to 95 per cent CaO) and ferric sulphate were also tested. Quicklime was used from Sept. 26 to Oct. 4, and ferric sulphate during January and a part of February, 1933, and also for a few days during 1932.

Summary of Results on Treatment of Raw Sewage by the Laughlin Process

An interpretation of what may be expected from the Laughlin process on raw sewage must be based on the results of the Dearborn Experimental Plant, 48 days of operation at the Dearborn West Side Plant and the Coney Island data. These are summarized in Table VI. The 26-day average is representative of a normal but somewhat weaker sewage.

A study of the daily results operating on raw sewage indicates that the

TABLE IV

SUMMARY OF DEARBORN OPERATION AND ANALYTICAL RESULTS

Operation Data

Date	Treated	Rate of Flow	Per Cent of Total E. S. Sludge	Detention Period, Hrs.	Settling Rate, Gal./Sq. Ft./ 24 Hrs.	Magnetite Filter Rate, Gal./Sq. Ft./ Minute	Chemicals Used for Sewage Treatment: Paper	Lime as CaO	Ferric Chloride	Ferric Sulphate	No. of Clarifiers Used
1932											
May	1.58	1.58	36	2.6	1100	0.84	430	1020	300		1
June	1.15	1.15	48	3.6	800	0.61	320	435	270		1
July (1)	1.02	1.53	40	2.7	1060	0.82	240	685	280		1
Aug.	1.46	2.20	29	1.9	1520	1.17	400	2730	400		1
Sept.	2.37	3.56	16	2.9	1240	0.95	400	1450	930		2
Oct.	3.09	4.65	10	1.8	1620	1.24	279	256	272		2
1933											
Jan. (2)	3.14	4.70	6	1.8	1630	1.25	154	192		185	2
Feb. (3)	2.85	4.28	7	1.9	1490	1.15	233	306	(4)	195	2

Analytical Data and Per Cent Removal

Date	Total Solids Inf., P. p. m.	Total Solids Eff., P. p. m.	Total Solids % Removed	Suspended Solids Inf., P. p. m.	Suspended Solids Eff., P. p. m.	Suspended Solids % Removed	% Inf.	Volatile Eff.	5-Day B. O. D. Inf., P. p. m.	5-Day B. O. D. Effluent, Unchl.	5-Day B. O. D. Effluent, Chlor.	5-Day B. O. D. Per Cent
1932												
May	1690	537	68	865	26	97	37	62	243	37		85
June	1286	612	52	690	24	97	38	68	223	37		83
July (1)	2260	517	77	1670	45	97	45	58	521	78		85
Aug.	2800	645	77	2330	43	98	36	49	668	58	66	91
Sept.	7140	753	89	6200	57	99	29	51	1305	54	56	86
Oct.	1758	720	59	1096	37	97	33	40	170	21	27	88

1933												
Jan.	1040	605	42	460	31	93	44	61	135	19		96
Feb.	927	580	37	195	20	90	52	63	162	22		86

Dissolved Oxygen, pH, Alkalinity and Per Cent Volatile Matter

Date	Dissolved Oxygen Eff., P. p. m.	pH Raw	pH E. S.	pH Eff.	Alkalinity Total Inf., P. p. m.	Alkalinity Effluent, Phenol	Alkalinity P. p. m., M. O.	Chorides Inf., P. p. m.	Chorides Eff., P. p. m	% Total Volatile Solids Inf.	% Total Volatile Solids Eff.
1932											
May	5.6	7.8	7.5	9.1	226	30	126	44	58	46	58
June	3.8	7.7	7.4	8.1	239	11	196	35	73	44	60
July (1)	5.0	7.7	7.0	8.5	134	23	79	37	70	34	54
Aug.	4.0	8.0	7.1	9.6	271	160	274	21	45	38	52
Sept.	2.5	7.8	7.1	8.3	261	14	157	18	45	31	59
Oct.	3.8	7.6	7.1	7.6	251	19	214	15	27	38	53
1933											
Jan.	5.9	8.3	6.9	7.5	236	0	224	21	22	47	43
Feb.	6.5	7.4	6.9	7.5	220	0	216	15	17	43	44

(1) July 23–31 on Composite E. S. Sludge and W. S. Sewage.
(2) Jan. Ferric Sulphate used instead of Ferric Chloride.
(3) Feb. Ferric Sulphate. Feb. 1–21—217 lb./m. g. Feb. 21–28—Ferric Chloride used 110 lb./m. g.
(4) All calculated to Ferric Sulphate.

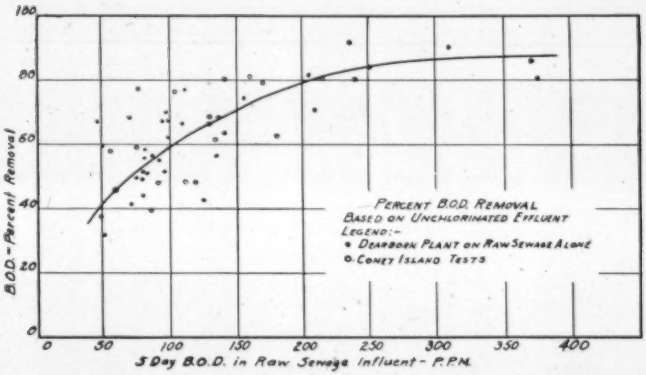

FIG. 4.—Curve Showing Per Cent B. O. D. Removal by Laughlin Process Without Chlorination as Found by Operation at Dearborn and Coney Island.

per cent removal varies according to the concentration of the sewage. The 5-day B. O. D. of the raw sewage influent in parts per million has been plotted against the per cent removal of B. O. D. as found in operation at

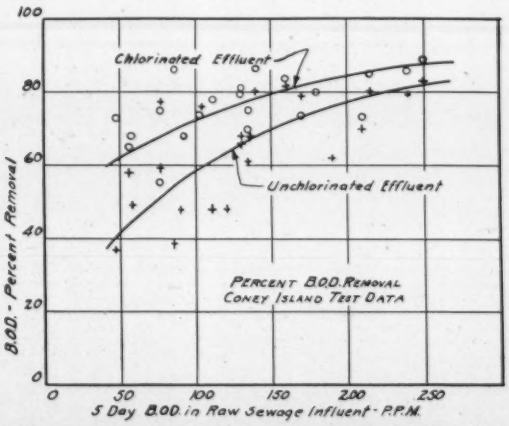

FIG. 5.—Coney Island Tests—Curve Showing Per Cent B. O. D. Removal with and Without Chlorination.

Coney Island and the Dearborn Treatment Works. Figure 4 shows the per cent reduction based on unchlorinated samples. Figure 5 compares the B. O. D. removal before and after chlorination as found in the Coney Island tests.

Table V

Average Composition of East Side Sludge and West Side Raw Sewage, Dearborn Sewage Treatment Works

	East Side Sludge May, 1932, to Feb., 1933	West Side Sewage May to Oct., 1932	West Side Sewage Nov., 1932, to Feb., 1933
Flow, M. g. d.	0.34	1.36	2.83
Suspended Solids	5740	367	106
Per Cent Volatile	39	44	45
Total Solids	6417	921	704
Per Cent Volatile	41	48	43
5-Day B. O. D.	1437	126	30
pH	7.1	7.8	7.5
Alkalinity	239	241	239
Chlorides	26	24	18

The average chemicals used in operation, shown in Table VI, for Dearborn and Coney Island, include a number of days when the sewage was dosed with greater amounts of chemicals than normally required. Table VII compares the results obtained with various amounts of chemicals and various concentrations of sewage.

Chlorination

Substantial reductions in 5-day B. O. D., from 25 to 40 per cent based on the unchlorinated effluent, were obtained by chlorination at the Dearborn Experimental Plant and at the Coney Island testing station. An average residual of 0.4 p. p. m. chlorine was maintained at Coney Island and 62 lb. chlorine per m. g. was used. Only 25 lb. of chlorine per m. g. was used at the Dearborn Experimental Station. Effluent at the Dearborn Plant was chlorinated until November, 1932, but no reduction in B. O. D. was effected. An explanation has been advanced attributing this fact to use of Prestolite lime. The writer, however, believes that the amount of chlorine normally used and the period of contact between chlorine and sewage was insufficient to produce a reduction. Excessive amounts of lime or ferric chloride, however, may have affected the action of the chlorine, as may be presumed from the September results when 73 lb. of chlorine per m. g. of effluent produced a residual chlorine of 1.5 p. p. m. without effecting a B. O. D. reduction. Table VIII shows the chlorine used and residual obtained as averaged by months.

Removal of Suspended Solids by Laughlin Magnetite Filter

Data on analyses made on samples taken below and above the Laughlin filter demonstrate its effectiveness in the removal of suspended solids, some

of which might normally be discharged in the effluent from chemical precipitation of sewage in plain sedimentation tanks having short detention periods. Table IX shows results of a test made at Coney Island to determine the efficiencies of settling and filtering through the magnetite sand

TABLE VI

SUMMARY OF OPERATING AND ANALYTICAL RESULTS ON RAW SEWAGE, LAUGHLIN PROCESS OF SEWAGE TREATMENT

	Dearborn				Coney Island	
	Experimental		Plant*			
No. of Days included	72		48	26	11	
Gallons per Day Treated	250-500,000		1,150,000	1,110,000	12,800	
Detention Period, Hours	1½ to 3		3.6	3.7	1.15	
Settling Rate, Gal./Sq. Ft./24 Hrs.			800	770	990	
Filtering Rate, Gal./Sq. Ft./Min.			0.61	0.59	0.87	
Chemicals Used per M. g.						
Paper	300		286	285	385	
Lime	600		460	245	900	
Ferric Chloride	200		265	235	161	
Chlorine	25				62	
Raw Sewage, P. p. m.						
Total Solids	639		950	694	1979	
Per Cent Volatile			52	53	47	
Suspended Solids	175		410	212	132	
Per Cent Volatile			62	65	80	
Ammonia Nitrogen	15					
Organic Nitrogen	2.9					
Chloride	56		32	33		
pH	7.3		7.8	7.8	7.4	
Alkalinity	336		232	244		
Dissolved Oxygen	1.1					
5-Day B. O. D.	100		222	112	132	
	(Unchlor.)	(Chlor.)	(Unchlor.)	(Unchlor.)		(Chlor.)
Effluent, P. p. m.						
Total Solids	494		520	507	1922	2028
Per Cent Volatile			52	56	38	37
Suspended Solids	26		32	20	21	12
Per Cent Volatile			76	80	57	60
Ammonia Nitrogen	14					
Organic Nitrogen	1.5					
Chloride	81		48	48		
pH	7.8		8.3	8.0	9.9	9.9
Alkalinity	323		203	200	235	256
Dissolved Oxygen	6.9		3.5	3.1	3.9	5.9
5-Day B. O. D.	55	23	46	38	41	28
Per Cent Removal						
Total Solids	23		45	27	5	3
Suspended Solids	86		92	91	84	92
Total Nitrogen	13					
5-Day B. O. D.	45	67	78	66	69	79

* No East Side sludge added to raw sewage during 48 days. The 26-day average excludes those days when sewage contained excessively high suspended solids, or when excessive lime was used.

in the Laughlin tank. About 250 pounds of ferric sulphate, 650 pounds of lime and 280 pounds of paper per m. g. was used in this test. Similar analyses made on samples taken above and below the magnetite filter at Dearborn during regular operation in May and June, 1932, indicated a

TABLE VII

COMPARISON OF EFFECT OF VARIOUS AMOUNTS OF LIME AND SEWAGE CONCENTRATION, LAUGHLIN PROCESS OF SEWAGE TREATMENT

Description	Rate of Flow, M. g. d.	Detention Period, Hrs.	Settling Rate, Gal./Sq. Ft./24 Hrs.	Chemicals Used, lb./M. g. Paper	Lime as CaO	Ferric Chloride	Suspended Solids Inf.	Eff. (Unchl.)	% Removed	% Inf.	Volatile Eff.	5-Day B. O. D. Inf.	Eff. (Unchl.)	% Removed
Dearborn														
0–300 Lb. Lime														
Av., 11 Days, June	0.93	4.5	630	298	180	265	191	18	90	64	83	114	40	65
Av., 14 Days, July	1.37	3.0	950	259	175	212	234	21	91	62	79	122	39	68
300–600 Lb. Lime														
Av., 4 Days	0.86	4.8	595	430	430	243	141	20	86	63	84	75	37	51
Av., 4 Days	0.90	4.6	625	500	500	400	863	26	97	54	83	300	51	83
600+ Lb. Lime														
Av., 2 Days	1.60	2.6	1120	360	806	296	197	15	93	64	72	150	35	77
Av., 2 Days	1.22	3.4	850	334	1280	259	609	30	95	59	58	263	54	79
Coney Island														
Av., 4 Days	0.0164	1.0	1396	294	688	115	153	24	84	79	57	137	37	73
Av., 7 Days	0.0127	1.3	901	440	1019	189	114	19	83	77	55	130	43	67

TABLE IX

CONEY ISLAND TEST ON EFFICIENCIES OF SETTLING IN LAUGHLIN TANK AND FILTERING THROUGH MAGNETITE FILTER

Test No.	Duration of Test, Hrs.	Gal. per Min. Sewage Treated	Detention Period, Hr.	Filtering, Gal./Sq. Ft. per Min.	Settling, Gal./Sq. Ft./24 Hrs.	Cleaner Mechanism Times Operated	Minutes On	Minutes Off	Suspended Solid, P. p. m. Raw Sewage Influent	Below Filter	Effluent	% Inf. to Below Filter (Settling)	Removed Below Filter to Eff. (Magn. Filter)
1	1.0	8.7	1.29	0.78	890	3	28	32	140	17	5	88	71
2	1.0	13.7	0.81	1.23	1400	5	49	11	120	59	4	51	93
3	1.0	11.8	0.95	1.06	1200	4	43	17	113	58	7	49	88

reduction of suspended solids of 71 per cent by sedimentation and 25 per cent by the magnetite filter based on influent. The effluent was 86.3 per cent lower in suspended solids than the liquor below the filter.

TABLE VIII

AVERAGE CHLORINE DOSAGE AND RESIDUAL AT DEARBORN

Date	Temp., ° C.	Chlorine, Lb./M. g. Sewage	Residual, P. p. m.	No. of Days Showing Zero Residual
May	13	32	..	..
June	16	34	0.13	19
July	19	34	0.18	17
Aug.	19	25	0.30	9
Sept.	18	73	1.50	1
Oct.	16	36	0.40	1

Production and Dewatering of Sludge

The sludge produced from the Laughlin process, chemicals required for conditioning and the capacity of vacuum filters needed depend on the solids content of the untreated sewage and the paper and chemicals applied for treatment. Although these are expected to vary for different sewages, data from one plant can be applied to another by a proper interpretation of the results. Data on production and handling of sludge at the Dearborn plant and the small-scale tests at Coney Island are available for estimating the quantities of sludge produced, chemical conditioner and dewatering equipment required for Laughlin type of sewage treatment. Table X shows a summary of the sludge data obtained at Dearborn.

Except for a few brief periods, during which only limited data are available, the Laughlin Plant at Dearborn handled the semi-septic sludge from the East Side Imhoff tanks. Prestolite lime was used for conditioning sludge, at first alone and later combined with ferric chloride. The low volatile content as well as the low B. t. u. value of the sludge produced at Dearborn may be attributed to the high percentage of fixed matter in both the East Side sludge and West Side sewage solids. Considerably more fixed matter is also added by the Prestolite lime, which contains about a third of a pound of other solids, besides calcium oxide, to every pound of dry solids. Satisfactory yields of sludge cake of low moisture content could be obtained on the vacuum filters by adding moderate amounts of lime to the sludge sumps for conditioning only when a heavy dosage of lime, paper and iron solution had already been applied to the influent of the clarifiers. Otherwise it was necessary to make up the deficiency by conditioning the sludge with large amounts of lime prior to dewatering.

It was found that by using ferric chloride in combination with lime for sludge conditioning, higher yields on the vacuum filters could be obtained, less lime was necessary and sludge could be filtered irrespective of the

TABLE X

SUMMARY OF SLUDGE DATA AT DEARBORN PLANT

Chemicals for Sludge Conditioning

Date	Flow Treated M. g. d.	Flow East Side % of Total	Lb. Chemicals per M. g. Sewage Treated Paper	Lime as CaO	$FeCl_3$	Tons per Month Dry Solids Filtered	Prestolite as CaO	Lb. Prestolite per Ton Dry Solids	Ferric Chloride Used Ton per Month	Ferric Chloride ($FeCl_3$) Lb./Ton Dry Solids
May	1.58	36	430	1020	300	231.1	24.9	198		
June (1)	1.15	48	320	435	270	180.3	20.1	223		
July (1)	0.95	0	252	460	260	87.4	9.5	217		
July (1)	1.02	40	240	685	280	60.7	8.6	282		
Aug.	1.43	29	400	2730	400	375.2	51.4	272		
Sept.	2.37	16	400	1450	930	209.2	26.6	256		
Oct.	3.09	10	279	256	272	407.1	83.4	411		
Nov. (2) (5)	2.73	9				320.0	37.5	234	10.9	68
Nov. (3)						15.7	12.0	1530		
Dec. (2)	2.95	8				248.6	31.9	257	8.3	67
Jan.	3.14	6	154	192	185 (4)	256.0	37.9	296	8.3	65
Feb.	2.85	7	233	306	195 (4)	169.0	19.8	233	4.5	53

Sludge Dewatering Data

Date	Wet Sludge % Solids	Wet Sludge % Vol.	Sludge Cake % Solids	Sludge Cake % Volatile	Sludge Cake B. t. u. Dry Basis	% Total Nitrogen	Lb. Dry Solids per Sq. Ft. of Filter per Hour
May	10.4	29.3	43.0	29.2	3230	0.90	1.9
June (1)	11.6	28.1	40.6	29.5	3440	0.74	3.9
July (1)	11.6	22.5	43.1	25.3	3390	0.83	4.0
July (1)	14.0	25.9	43.5	26.6	3460	0.78	4.6
Aug.	13.6	26.8	47.1	27.0	3530	0.74	5.3
Sept.	11.5	23.0	44.6	24.0	3570	0.74	4.9
Oct.	14.2	18.0	46.3	18.0	3490	0.71	6.0
Nov. (2) (5)	12.3	28.7	39.0	29.0			7.8
Nov. (3)	12.6	26.0	41.0	26.0			2.9
Dec. (2)	11.8	29.0	38.0	29.0	3700		7.3
Jan.	11.7	32.0	38.1	33.0	3740		7.4
Feb.	10.9	34.0	37.0	35.0			7.6

(1) Sewage alone part of June and July 1–22. Composite July 23–31.

(2) Sewage and sludge in separate clarifiers, includes sludge from both conditioned with ferric chloride and Prestolite. Chemicals used for sewage irregular. Small amounts considered negligible.

(3) Two days using Prestolite alone.

(4) Ferric Sulphate.

(5) Chemicals used on sludge drawn from clarifier handling only raw sewage:

Total Sewage Treated	79 million gallons
Sludge Filtered	30,000 gallons
Prestolite Used	27,300 pounds, 105 lb. CaO per M. g. Sewage Treated
Ferric Chloride Used	1,880 pounds, 24 lb. $FeCl_3$ per M. g. Sewage Treated

No separate record of sludge moistures from which to figure chemicals on basis of dry solids.

dosage applied to the clarifiers. Ferric chloride has therefore been used for this purpose since November. It is added from carboys at the same time sludge and lime solution is being pumped into the sludge sump. Some mixing and stirring is obtained with air discharged through a perforated pipe at the bottom of the sump. This is not very effective, and the need for a properly designed device for coagulation and conditioning of sludge is evident, if the greatest possible economy and best results in the use of ferric chloride and lime for this purpose is to be realized.

TABLE XI

SUMMARY OF DEWATERING TEST, CONEY ISLAND TESTING STATION

Depth of Laughlin Clarifier	5.0 Feet
Sludge Drawn from Clarifier	4.0 to 8.0 Per Cent Solids
Filtering Area on Oliver Filter	3.1 Sq. Ft.
Sludge Applied to Filter	5.0 Per Cent Solids
Lime Conditioner Used 3.8 Per Cent of Dry Solids:	
Cake Produced by Filter	73.1 Per Cent Moisture
Cake per Sq. Ft. of Filter per Hr.	4.2 Pounds
B. t. u. of Cake (Dry Basis)	4570
Lime Conditioner Used 8.1 Per Cent of Dry Solids:	
Cake Produced by Filter	70.6 Per Cent Moisture
Cake per Sq. Ft. of Filter per Hr.	3.9 Pounds
B. t. u. of Cake (Dry Basis)	4120
Lime Conditioner Used, 50 Per Cent of Dry Solids:	
Cake Produced by Filter	70.2 Per Cent Moisture
Cake per Sq. Ft. of Filter per Hr.	3.3 Pounds
B. t. u. of Cake (Dry Basis)	3850

Table XI is a summary of the sludge data obtained at Coney Island. The high moisture content of the sludge from the clarifier is due to its shallow depth, and the tests were on too small a scale and of too short duration to indicate the sludge handling efficiencies and moisture content that may be expected on larger units. The Dearborn data are more applicable for that purpose. The Coney Island sludge was of higher B. t. u. value than the Dearborn sludge. A decrease in B. t. u. value is noted with the increase of lime conditioner used.

The quantity of sludge produced depends on the suspended and total solids in the sewage and the chemicals added. Table XII shows the actual solids removed as sludge, suspended solids removed and sludge calculated from total solids and chemicals added. The data includes operation only on raw sewage at Dearborn and Coney Island.

The sludge cake produced at Dearborn has been put in several piles on the grounds near the treatment plant. This method of disposal has thus far been satisfactory without creating a nuisance. Incineration is being considered as a more permanent means of disposal of the Dearborn sludge.

An incinerator will be installed when funds are made available. Meanwhile some small scale tests in New York on incineration have been reported as satisfactory. Owing to the fact that excess lime is desirable in the sludge to prevent decay when piled on the grounds, operation has not been with the view in mind of using the least possible lime for filtration. With incineration as the ultimate disposal, only sufficient lime to properly condition the sludge would be necessary.

TABLE XII

SUMMARY OF SOLIDS REMOVED AND SLUDGE PRODUCED OPERATING ON RAW SEWAGE ALONE AT DEARBORN AND CONEY ISLAND

Description	Coney Island		Dearborn July 1-22, 1933	
	Parts per Million	Lb. per M. g. Sewage Treated	Parts per Million	Lb. per M. g. Sewage Treated
Suspended Solids				
Inf.	132		494	
Eff.	21		25	
Removed	111	907	369	3070
Total Solids				
Inf.	1979		957	
Eff.	1912		448	
Removed	67	484	509	4230
Chemicals Added				
To Sewage		1446		1138
To Sludge-Lime		0		1440
Total Solids Removed Plus				
Chemical Added		1930		6808
Solids Removed as Sludge		1615		8600

Construction and Operation Cost Estimates for Typical Sewage

Owing to the unusual problem of handling both sewage and sludge, the Dearborn costs, as a whole, cannot be applied directly to a plant for treating normal sewage. By segregation of the various equipment in use, such as Laughlin clarifiers, vacuum filters, pebble mills, labor employed, etc., and translating their capacities into terms of normal sewage, it has been possible to make estimates both as to construction and operation. These estimates are based upon a modification of the results of operation at Dearborn and Coney Island, chemicals used and flocculation and other tests in the laboratory. In making studies on suitability and costs of the Laughlin process for various communities in Michigan it was found that cost varied depending on many local conditions, but particularly on size of plant, hydraulic conditions, nature and composition of sewage and quality of effluent required. It is therefore preferable not to quote general cost figures, without first determining the conditions and requirements that must be met in each case. Table XIII shows the degree of treatment

expected and the costs estimated and submitted as proposals to two municipalities, A and B. This table is included to give a general idea of construction and operation costs of this type of treatment for such condi-

TABLE XIII

DEGREE OF TREATMENT AND ESTIMATED COSTS OF LAUGHLIN PROCESS

Municipality	A	B
Sewerage System	Combined	Separate
Population:		
Present	56,000	38,000
Design Basis	62,000	50,000
Avg. Flow, M. g. d.:		
Present	7.4	2.5
Design Basis	9.3	4.5
Design Basis:		
Gal. per Cap., Avg.	150	90
Av. Detention Period, Hrs.:		
Flocculators	0.5	0.5
Laughlin Clarifiers	1.5	1.5
Raw Sewage:		
Susp. Solids, P. p. m.	150	270
Lb. per Cap. per Year	68	60
5-Day B. O. D., P. p. m.	110	390
Lb. per Cap. per Day	0.14	0.26
Effluent (Chlorinated):		
Susp. Solids, P. p. m.	15	27
5-Day B. O. D.	25	58
Chemicals, Lb. per M. g. of Sewage:		
Sewage: Lime	320	600
Paper	300	300
Ferric Chloride	180	225
Chlorine	50	75
Sludge: Lime	100	200
Ferric Chloride	25	50
Method of Sludge Disposal	Incineration	Dumped by Trucks
Total Cost of Plant	$382,000*	$260,000
Annual Charges:**		
Total	84,800	60,700
Bond Retirement and Interest	29,100	19,800
Operation, Maintenance and Repairs	55,700	40,900
Per M. g.:	28.00	47.60
Bond Retirement and Interest	9.60	15.50
Operation, Maintenance and Repairs	18.40	32.10
Per Capita	1.44	1.38
Bond Retirement and Interest	0.49	0.45
Operation, Maintenance and Repairs	0.95	0.93

* Includes pumping Station.

** Average of Present and Design Basis.

tions as are indicated and should not be confused with already published figures applying only to the needs of Dearborn.

Effect of Dearborn Effluent on Fish Life

A series of 5 experiments[4] to determine the effect of Laughlin effluent on fish life were made by Dr. Carl L. Hubbs in the laboratory of the Institute for Fisheries Research of the University of Michigan. Five gallons of unchlorinated effluent was composited over a period of 3 hours with samples taken every half hour, during which the clarifiers were operated on raw sewage. This was taken to Ann Arbor and used for the fish tests. Table XIV shows the average analytical data of influent and effluent. Sewage was treated at the rate of 3.4 m. g. d. amounting to a detention period of 3.5 hours. The coagulants used were 194 lb. paper, 270 lb. CaO and 245 lb. $FeCl_3$ per million gallons.

TABLE XIV

COMPOSITION OF SEWAGE TREATED AND RESULTANT EFFLUENT USED FOR FISH TEST

	Inf., P. p. m.	Eff., P. p. m.
5-Day B. O. D.	185	37
Total Solids	740	518
Per Cent Vol.	36	33
Suspended Solids	296	30
Alkalinity	285	228
Chlorides	22	56
pH	7.3	8.0

The fish used were half grown "guppies," rather resistant tropical fish; and "minnows and shiners," delicate species taken from a creek near Ann Arbor. Tests were made in effluent, undiluted and diluted with various amounts of their filtered aquarium water. The resistance of the fish was tested in these various solutions at temperatures approximating winter, spring and summer conditions. First, fish were added to solutions containing effluent in relatively fresh conditions and later to solutions containing effluent which had stood for about 35 hours. Air was blown into some of the solutions both before and during the test, while in duplicate solutions no air was added before or after the fish were put into the solution. Control solutions, containing no effluent, in which the fish were subjected to the same conditions as those in the solutions containing effluent, were set up in each case for comparison.

The guppies survived at summer temperatures in solutions made up of 67 per cent relatively fresh effluent, even when unaerated during the test, but did not survive in solutions containing more than 33 per cent effluent which had stood for about 35 hours without aeration and not aerated during the test.

The minnows and shiners lived on for 2 days at spring temperatures in 100 per cent fresh effluent unaerated and somewhat longer in higher dilutions, but were killed in solutions containing as low as 5 per cent effluent which had stood unaerated for 38 hours and was not aerated during the test. Fish losses were also high in the control solutions which had stood a similar length of time and correspondingly unaerated. This indicates the effect on fish life of solutions standing considerable time without aeration.

Although under conditions of limited dilution and considerable stagnation harmful effects may occur, there was nothing toxic to fish life in the effluent tested. It is difficult to determine from these tests the exact safe dilution necessary, but it is evident that under ordinary conditions the Laughlin effluent may not be considered harmful to fish life.

Discussion

There appears to be a revival of interest in the use of chemicals for sewage purification. A better understanding of the use and action of coagulants and the introduction of mechanical equipment for handling and dewatering sludges have removed many of the difficulties encountered in earlier work on application of chemicals for sewage treatment. The Laughlin process as installed at Dearborn is a contribution to modern chemical sewage treatment. The magnetic filter and cleaner reduces the time required for sedimentation by effecting the rapid and efficient removal of fine floc, thereby introducing an improved departure from the old conception of chemical precipitation which required many hours of sedimentation.

Improved efficiency and more economical use of paper, lime and iron solutions can be accomplished by proper proportioning according to flow and concentration of sewage, by use of flocculators for mixing and formation of a suitable floc, and by sludge conditioning devices. Work thus far at Dearborn and at Coney Island has demonstrated the need and value of such improvements.

The Laughlin process is effective in precipitating and removing suspended, colloidal and some dissolved matter, thus producing a well clarified effluent. The final B. O. D. of the effluent is mostly due to organic matter remaining in solution. Measured in parts per million, the effluent contains less suspended solids than B. O. D. For this reason comparison of effluents must be made from the standpoint of oxygen resources in a stream, taking into consideration the effect of suspended solids as well as B. O. D.

The Laughlin process affords an economical means of sewage treatment for conditions where a well clarified effluent is essential, but oxidation or nitrification is unnecessary. By a proper adjustment of chemicals it is possible to vary the degree of treatment obtainable within moderate limits, thereby meeting the needs of seasonal fluctuations of river flow. This type

of treatment has been approved by the Michigan State Department of Health as being suitable for conditions at Ann Arbor.

Conclusions

A comprehensive study of the data on the Laughlin process may be summarized as follows:

(1) This process is suited for conditions where the oxygen in the receiving body of water is adequate to satisfy the demand of the organic solids carried in solution by the effluent.

(2) It is possible to obtain from 65 to 85 per cent removal of 5-day B. O. D. and a reduction of 85 to 95 per cent suspended solids depending on the concentration of raw sewage and chemical dosage.

(3) Satisfactory results can be obtained in a working range of pH 8.0 to 8.5 which is not inhibitory to biologic or fish life.

(4) Chlorination sterilizes and reduces the B. O. D. by 25 to 40 per cent, based on unchlorinated effluent.

(5) Sludge dewaters satisfactorily when lime is used for conditioning. Ferric chloride improves the rates on the filter and reduces the amount of lime needed. The amount of chemicals required for sludge conditioning is dependent on the chemical dosage used for raw sewage.

(6) Rates of sludge filtration on vacuum filters average 6 to 8 pounds of dry solids per square foot per hour. Sludge cake of 60 to 70 per cent moisture is discharged from the filter.

(7) Sludge cake produced is suitable for incineration or by disposal on waste land.

References

[1] Mark B. Owen, "Novel Sewage Treatment Process Developed for Dearborn, Michigan," *Water Works and Sewerage*, **78**, 279 (October, 1931).

[2] Mark B. Owen, "Notes on Operation of the Dearborn Sewage Treatment Plant," *Water Works and Sewerage*, **79**, 351–4 (October, 1932).

[3] Hurwitz and Zack, "Performance of Laughlin Process of Sewage Treatment," *Water Works and Sewerage*, **80**, 117–20 (April, 1933).

[4] Dr. Carl L. Hubbs, "Effect on Fish Life of Effluent from New Sewage Treatment Plant at Dearborn, Michigan," Institute of Fisheries Research, University of Michigan, *Report* **194.**

The Use of Sludge Digestion Gas for Power Production. Cause and Effect of Variations in Composition of Gas

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Introduction

The primary object of sludge digestion is to convert the sewage solids to an inodorous, easily dried residue—not to produce gas. However, collection of the gas is justified to prevent odors and to heat the digestion tanks, thereby shortening the digestion period. The gas has been successfully used as a fuel for internal combustion engines at several plants in Europe, but I know of only three full-scale American plants that so use the gas, Rockville Centre, N. Y.,[1] Charlotte, N. C.,[2] and Springfield, Illinois. At these plants the engine cooling water and exhaust gases are utilized to heat the digesters; sufficient heat is developed to maintain adequate digestion temperatures, thus making the scheme attractive. At Rockville Centre it has worked quite satisfactorily but at Charlotte the cost of maintaining the engine practically wipes out the value of the power produced. The Springfield installation is reported to be quite efficient and successful.

The first year's operation of the Salinas, California, plant, which combines the activated-sludge process[3] with separate sludge digestion,[4] showed that additional air was needed for the activated-sludge process and that heating the digester would improve its performance. The installation of a gas engine to drive an additional blower and the use of the engine cooling water to heat the digester appeared promising, but because of the limited use of that scheme in America and because of the varying degrees of success with which it had met an extended study of all phases of the plan was made before deciding whether or not it should be tried at Salinas. A review of current literature and some experiments were made to determine the probable effects of variations in the composition of the gas upon the reliability and maintenance costs of an internal combustion engine. The following paper contains the results of that phase of the investigation.

Variations in the Composition of the Gas

The literature contains many analyses of sludge digestion gases which show that the gases from different types of digestion tanks and from different sewages usually contain the same constituents but that the relative amounts of these may vary over wide limits. In this case we are more interested in the variations in the composition of the gas from one plant than from different plants. Table I contains such data for a few plants. Although these data are rather meager they will suffice to show that the

TABLE I

VARIATIONS IN THE COMPOSITION OF SLUDGE DIGESTION GAS

References	Location and Type of Plant		Percentage Volumetric Composition								Total Heat Value, B. t. u. per Cu. Ft.
				Methane CH_4	Carbon Dioxide CO_2	Nitrogen N_2	Oxygen O_2	Hydrogen Sulphide H_2S	Hydrogen H_2	Carbon Monoxide CO	Illuminants	
5, 8, 9, 12	Decatur, Ill., Imhoff	Regular Analyses over 2-Year Period	Max.	74.0	34.0	14.1	0.1	0.95	4.0			
			Min.	55.0	16.0	2.6	0.0	0.17	0.0			
			Av.	68.0	22.0	6.0	0.0		2.0			
5, 7	Chicago, Ill. (Calumet), Imhoff	1 Year of Daily Analyses	Max.	84.1	26.5	18.3	0.8					849
			Min.	64.0	8.2	2.0	0.1					651
			Av.	74.4	14.2	11.1	0.3					751
8, 9	Urbana, Ill., Imhoff	7 Analyses over 6-Month Period	Max.	70.7	22.6	23.2	0.6		0.0			
			Min.	60.0	10.0	11.2	0.0	0.0				
8, 9	Urbana, Ill., Septic	4 Analyses over 12-Month Period	Max.	78.0	17.0	15.9	0.0	0.5	5.0			
			Min.	64.3	13.6	5.0			0.0			
8, 9	Highland Park, Ill., Imhoff	3 Analyses on 1 day	Max.	78.2	24.7	18.5	0.0		0.0			
			Min.	71.3	3.3	3.3						
4	Salinas, Calif., Digester	4 Analyses over 3-Month Period	Max.	63.8	30.1	11.1	1.8	18.0	0.0	0.0	0.0	723
			Min.	59.3	9.4	6.4	0.5	0.0				603
10	Milwaukee, Wisc., Digester (screenings) Regular Analyses over 214 Days		Max.	58.0	44.6	26.2	3.6		3.0	3.2	2.8	
			Min.	34.9	29.0	0.6	0.2		0.0	0.3	0.6	
16	Milwaukee, Wisc., Digester (activated sludge) Weekly Analyses over 288 Days		Max.		35.1		7.9					
			Min.		17.2		3.4					
5, 6	Birmingham, England, Digester		Max.	77.0	30.0	3.2	0.4					700
			Min.	67.0	18.1	3.0						625
8	Emscher District, Germany, Imhoff		Max.	85.0	30.7	4.6	0.9					
			Min.	64.8	7.0	0.4	0.2					
5, 11	Halle Germany, Imhoff		Max.	77.3				0.58				
			Min.	63.9				0.076				
			Av.	72.9	24.6	1.6	0.6					729

composition of the gas varies through quite wide limits and that such fluctuations may occur in rather short periods of time. In general it seems probable that the daily variations in the composition of the gas are as great as are those in the quantity of gas. Specifically we might expect the principal ingredients to vary somewhat as follows: methane 60 to 80 per cent, carbon dioxide 10 to 30 per cent and nitrogen 1 to 15 per cent. The gas usually contains detectable amounts, and often measurable amounts, of hydrogen sulphide. Frequently it may contain small amounts of hydrogen or oxygen. The presence of oxygen probably indicates dilution with air and in such cases the nitrogen content may exceed 15 per cent due to this dilution. Carbon monoxide and illuminants are seldom present.

Comparison of Digestion Gas with Other Gaseous Fuels

Table II gives the volumetric composition (omitting gases present in minute amounts) and physical and chemical properties of two hypothetical digestion gases and several of the gases more commonly used as fuel. The composition of the latter may vary considerably in different localities.

Heat Value.—When the heat value of a fuel gas is determined in a calorimeter the products of combustion are cooled to the original temperature of the air-gas mixture. Most of the water vapor formed by the combustion of the free and combined hydrogen in the gas is condensed by this cooling. The measured quantity of heat, therefore, includes the latent heat of the water vapor recovered during condensation. The low heat value is the heat value of the gas when none of the water vapor formed by combustion has been condensed. This is the heat value on which gas engine efficiencies are usually based, since a gas engine cannot utilize the latent heat of the water vapor.

An inspection of Table II shows that there is considerable range in the heat value of gaseous fuels. The poorer digestion gas, B, has a heat value about equal to the average of the other fuels while gas A has a heat value higher than any but natural gas. When the gases are mixed with sufficient air to supply just the oxygen necessary for complete combustion the heat values of the resulting mixtures are all practically the same, with the exception of the water and producer-gas mixtures. Figure 1 shows the effect of variations in the methane content of the digestion gas on the heat value of the theoretical mixture.

Air Requirements.—The amount of air chemically necessary for combustion depends solely upon the amount and kind of combustible ingredients in the gas. Figure 1 shows how this amount varies with varying methane content of digestion gases. In practice more than the theoretical amount of air is used. If only that amount were used combustion would not be complete, but if much in excess is used combustion, while complete, will be slow and so will lower the engine efficiency. The amount

TABLE II

VOLUMETRIC COMPOSITION AND SOME CHEMICAL AND PHYSICAL PROPERTIES OF SLUDGE DIGESTION GASES COMPARED WITH THOSE OF THE MORE COMMON GASEOUS FUELS

	Sludge Digestion Gas "A"	Sludge Digestion Gas "B"	Natural Gas	Oil Gas	Coal Gas	Water Gas (blue)	Producer Gas
Percentage Composition by Volume							
Hydrogen H_2	0.0	0.0	2.0	58.4	46.0	48.0	13.0
Methane CH_4	80.0	60.0	93.0	28.8	40.0	2.0	0.8
Carbon Monoxide CO	0.0	0.0	0.6	4.4	6.0	38.0	27.0
Illuminants as Ethylene C_2H_4	0.0	0.0	0.3	3.4	5.0	0.0	0.0
Oxygen O_2	0.0	0.0	0.4	0.0	0.5	0.5	0.5
Carbon Dioxide CO_2	15.0	30.0	0.2	1.2	0.5	6.0	4.0
Nitrogen N_2	5.0	10.0	3.5	3.8	2.0	5.5	54.7
Total Heat Value, B. t. u. per standard cu. ft.	803	602	946	549	651	301	138
Net Heat Value, B. t. u. per standard cu. ft.	730	548	862	492	588	276	131
Weight per standard cu. ft., pounds	0.055	0.067	0.043	0.025	0.030	0.043	0.066
Specific heat at constant volume	0.346	0.272	0.438	0.598	0.531	0.311	0.295
Cu. ft. air chem. necessary to burn 1 cu. ft. gas	7.6	5.7	9.0	4.7	5.8	2.2	1.0
Explosive Limits:							
Maximum cu. ft. air per cu. ft. of gas	15.1	11.1	18.2	21.1	20.8	15.1	5.5*
Minimum cu. ft. air per cu. ft. of gas	6.0	5.1	6.7	3.0	3.8	1.3	0.6*
Theoretical Gas-Air Mixtures:							
Net heat value, B. t. u. per standard cu. ft.	85	82	86	84	85	92	66
Weight per standard cu. ft., pounds	0.074	0.075	0.073	0.067	0.069	0.066	0.071
Specific heat at constant volume	0.184	0.182	0.185	0.243	0.188	0.198	0.227
Theo. temp. rise upon combustion, ° F.	6280	6030	6380	5150	6520	7060	4080
Vol. of inert gas in mixture, per cent	72.2	73.3	71.5	66.0	67.8	57.9	68.8

* Not corrected for retarding action of N_2 in Producer Gas.

of excess air usually used ranges from 35 per cent of that chemically necessary with producer gas to 55 per cent with natural gas; 40 to 45 per cent is usually used with the other fuels listed in Table II. Possibly about 50 per cent excess air would give best results with digestion gas.

Explosive Range.—Since it is neither possible nor desirable to regulate the air supply to an engine so that there shall always be present exactly the amount chemically necessary for combustion an important characteristic of a fuel is its explosibility with an excess or deficiency of air. Other things being equal, that fuel is best which will permit the largest variation of the ratio of air to fuel without failure to ignite.

The determination of the explosive limits of a gas is difficult and is complicated by the marked effect of the apparatus used. For that reason the results of different investigators are not in complete accord. Coward and Jones[13] have made an exhaustive study of this subject and their results form the basis of the following paragraph.

Table II gives the maximum and minimum amounts of air with which one cubic foot of the different gases will form explosive mixtures under ordinary atmospheric temperatures and pressures. In general, increases in temperature and pressure appear to widen the explosive range slightly. It will be noted that the explosive range is quite narrow for digestion gases and, as shown in Figure 1, narrows considerably as the methane content of the gas decreases. If an engine were operating on a gas of high methane content and using about 50 per cent excess air a sudden drop in the methane content of the gas might result in a non-explosive mixture, but inasmuch as the variations in the methane content of the gas are probably quite gradual frequent adjustment of the gas-air mixture will avoid this possibility.

Inert Gases.—Carbon dioxide and nitrogen act as diluents and so increases in the amount of these ingredients have a marked effect on the heat value of the gas air mixture. This effect on the theoretical mixture is shown in Figure 1; since more than the theoretical amount of air is used in the actual mixture this effect of the inert gases is not so marked in the actual mixtures.

Large amounts of inert ingredients narrow the explosive range of the gas; they affect the minimum amount of air more than the maximum amount. Figure 1 shows this effect for digestion gases. As will be observed carbon dioxide has a slightly greater effect than nitrogen in this respect.

Temperature of Combustion.—In the ideal engine with the ideal fuel, *i. e.*, instantaneous explosion, the pressure resulting from the explosion depends primarily upon the temperature rise during combustion. This depends not only upon the heat value of the mixture but also upon the specific weight and specific heat of the mixture. These values for the theoretical mixtures under ideal conditions are shown in Table II. The actual temperature rise will be much less due to (*a*) the use of excess air,

(*b*) heat losses in the engine, and (*c*) expansion of the mixture during non-instantaneous combustion. It will be noted that in this respect the digestion gases are only slightly inferior to natural and coal gases.

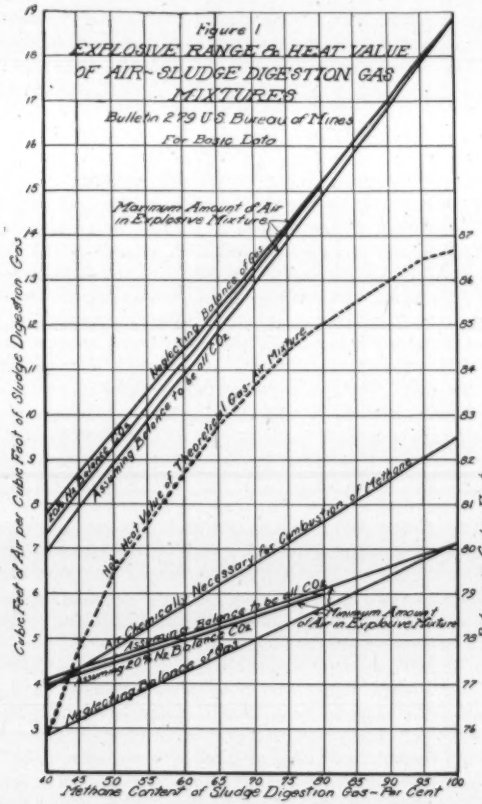


Figure 1
EXPLOSIVE RANGE & HEAT VALUE OF AIR-SLUDGE DIGESTION GAS MIXTURES
Bulletin 279 U.S. Bureau of Mines For Basic Data
Maximum Amount of Air in Explosive Mixture
Neglecting Balance of Gas
Assuming Balance to be all CO2
Mixtures of Digestion Gas & Air
Net Heat Value of Mixtures
Air Chemically Necessary for Combustion of Methane
Assuming Balance to be all CO2
Assuming 20% N2 Balance CO2
Neglecting Balance of Gas
Maximum Amount of Air in Explosive Mixture
CO2 No Balance CO2
Cubic Feet of Air per Cubic Foot of Sludge Digestion Gas
B.t.u. per Cubic Foot
Methane Content of Sludge Digestion Gas - Per Cent

Compression.—The actual explosion in a gas engine is far from instantaneous. Increased compression materially reduces the duration of the combustion. If gasoline engines are to be operated on gaseous fuels it is necessary to equip them with special high compression heads to obtain

economical operation, and even then they will develop 5 to 15 per cent less power than when operated on gasoline. Dilution of the explosive mixture with excess air or inert gases increases the time of combustion. As can be seen from Table II there is only slightly more inert gas in either of the digestion gas mixtures than in the natural gas mixture. It seems probable that engines designed to use natural gas as a fuel will give almost as good results when utilizing a sludge digestion gas similar to either A or B.

Effect of Gases Usually Present Only in Minute Amounts

As may be seen from Table I, digestion gases frequently contain small amounts of oxygen, hydrogen and hydrogen sulphide. Carbon monoxide and illuminants (ethylene or ethane) are usually absent but may be present in particular cases. Water vapor may also be present. The effects of these various gases on the operation of an internal combustion engine will now be briefly considered.

Oxygen in the gas decreases the amount of oxygen that must be furnished for combustion, but otherwise has no effect. The presence of more than one per cent of oxygen may indicate dilution of the gas with air.

Hydrogen has a lower heat value, requires less air for combustion and has a wider explosive range than methane. The presence of large quantities of hydrogen in the fuel makes an engine peculiarly liable to premature ignition.

Carbon monoxide is similar to hydrogen rather than to methane as regards its heat value, combustion requirements and explosive range.

Illuminants such as ethane and ethylene have higher heat values and require more air for combustion than methane. The presence of small amounts of illuminants in the gas would increase its heat value slightly but because the air required for combustion would also be increased, the heat value of the ideal mixture would be unchanged or slightly reduced. The maximum amount of air with which the gas would form an explosive mixture would be increased slightly while the minimum amount would remain constant or be slightly decreased.

Hydrogen sulphide is frequently not reported in analyses of digestion gases, although Buswell[9] states that it is detectable in most gases. At Halle,[11] Germany, the gas usually contains from 0.076 to 0.58 per cent hydrogen sulphide. Although an attempt is made to reduce the H_2S by passing the gas through tanks filled with bog iron ore before using it for an engine fuel, its presence has proved injurious to the motor; it is particularly harmful to the pistons and cylinder walls. While hydrogen sulphide itself is somewhat corrosive, one of the chief objections to its presence in a fuel is that its products of combustion, water and sulphur dioxide unite to form an acid which is much more corrosive. Since any form of sulphur in the fuel would produce sulphur dioxide as a combustion product any form

of sulphur would be just as objectionable as hydrogen sulphide in the fuel. But, because practically all of the H_2S may be removed from commercial gas while the total amount of sulphur present is not wholly within the control of the producer, the Bureau of Standards[14] recommends the permission of only a trace (about 0.0008 per cent by volume) of hydrogen sulphide while 30 grains of total sulphur per 100 cu. ft. of gas are permitted. About 0.05 per cent H_2S by volume would be equivalent to 30 grains of sulphur per 100 cu. ft. So it would appear that if all the sulphur in sludge digestion gas is present as hydrogen sulphide, a maximum of 0.05 per cent could be present without making the gas more corrosive than ordinary manufactured gases which have been successfully used in internal combustion engines. Walraven[29] quotes the U. S. Bureau of Mines as stating that 0.04 per cent sulphur does no harm, 0.151 per cent does considerable harm and 0.458 per cent does very great harm; probably a sulphur content of 0.1 per cent would cause no appreciable injury. A volume of about 0.07 per cent H_2S in the gas would be equivalent to 0.1 per cent total sulphur by weight. Some engine experts have advised me that 0.1 per cent of hydrogen sulphide by volume may be present without causing trouble and that even somewhat more may be present if the engine oil is changed quite frequently.

In commercial gas manufacture the hydrogen sulphide is generally removed by passing the gas through a bed of hydrated ferric oxide and shavings. The ferric oxide reacts with the hydrogen sulphide to form ferrous oxide, water and free sulphur. The shavings serve merely to keep the mass open and permit the free passage of the gas through it. Organic sulphur compounds are usually not removed in this manner and no easy or economical method of removing them has been discovered. Due to the difficulty and expense of removing hydrogen sulphide from the comparatively small amount of gas produced by sludge digestion it probably will not be practical to utilize the gas for power production if much in excess of 0.1 per cent by volume of that ingredient is present.

Water vapor has a high specific heat and so if it is not removed by condensation before the gas is utilized it may cause a large heat loss. If the moisture in the gas originated as droplets of mist expelled into the atmosphere of the digester by the ebullition of the gas or by other mechanical means instead of as true water vapor it may contain sulphate salts in solution. If these salts reach the engine they may be cracked by the high temperature and lose part of their sulphur. This sulphur will then be just as harmful as that reaching the engine as hydrogen sulphide. Probably very little sulphur reaches the engine in this manner, but when the H_2S content is near the permissible maximum this possibility should be considered. If condensate is allowed to collect and remain in the pipe lines it will not only reduce their capacity but will hasten their corrosion.

Hydrogen sulphide and carbon dioxide dissolve in water to form hydrosulphuric and carbonic acids. Both of these acids are more corrosive than the gases from which they are formed. Then, too, the condensate forms a medium for bacterial growths that are capable of converting the hydrogen sulphide or sulphate salts into sulphuric acid, which is still more corrosive.

Causes of Variations in Composition of Sludge Digestion Gases

Since the amounts of the various components of digestion gas may vary over wide limits and some of these variations may affect the maintenance and operation of a gas engine, a knowledge of the causes of these variations might be of value to one attempting to utilize the gas for power production. Inasmuch as sludge digestion processes are only partially understood there are many conflicting statements in the literature, but I have attempted to summarize some of the causes of these variations in the following paragraphs.

Composition of the Sludge.—The digestion of carbohydrates, cellulose, fats and proteins produces methane, carbon dioxide and, in many cases, small amounts of hydrogen. Buswell and Boruff[28] state, however, that fats and proteins are the principal sources of methane. Rudolfs and Heisig[10] state that carbonaceous matter produces large quantities of carbon dioxide and, therefore, it is logical to expect the carbon dioxide content to increase (and hence the methane to decrease) as the ratio of carbon to nitrogen in the sludge is increased. The extremely high carbon to nitrogen ratio in Milwaukee[10] fine screenings may explain the presence of carbon monoxide and illuminants in that gas while they are not found in normal sludge digestion gas.

Rudolfs and Heisig[15] found that in the digestion of activated sludge the carbon dioxide content of the gas varied with the rate of digestion of the grease present. But it does not follow that a high grease content will result in an increased carbon dioxide production, for Keefer and Kratz[16] and Heukelekian[17,18] have shown that, although a high fat content resulted in increased gas production, the composition of the gas was practically unchanged. Buswell and Boruff[28] state that "of the various constituents greases, fats and soaps furnish the best quality (62 to 75 per cent methane) and greatest quantity of gas. . . . The above considerations emphasize the advisability of digesting all grease if mechanically possible."

Bach[19] states that the nitrogen in the gas probably results in part from the decomposition products of proteins and urea and in part simply remains after the exhaustion of the oxygen in the dissolved air drawn into the digestion chamber with the sludge. Buswell and Boruff[28] state that it is impossible to account for the nitrogen found in the gas from any source other than the air. If part of the nitrogen results from the digestion of nitrogenous matter in the sludge a decrease in the ratio of carbon to nitrogen

might result in an increase in nitrogen production, but since sludge loses only a small amount of its nitrogen during digestion (Rudolfs[30] reports 6.5 to 17.0 per cent loss during prolonged digestion) there is no likelihood of this increase offsetting the decrease in carbon dioxide production.

Hydrogen sulphide may result from the reduction of sulphur dioxide, sulphates or albuminous substances. Sulphur dioxide is seldom found in sewage and even less frequently in sludge. Most sulphates found in sewage are in solution and so, although they constitute the principal source of the H_2S produced in sewers, the greater portion of them do not enter the digestion chamber, as shown by Table III, and hence are not the major source of this component of sludge digestion gas. Bach[19] considers albuminous substances to be the principal source of hydrogen sulphide.

TABLE III

AVERAGE SULPHATE CONTENT OF NINE ANALYSES OF WATER AND SEWAGE AT SALINAS, CALIFORNIA

	P. p. m.
Domestic Water Supply	47
Crude Sewage	113
Settled Sewage	115
Activated Sludge Effluent	120

Although sulphates are not the principal source of hydrogen sulphide in digestion gases, Rudolfs, Baumgartner, Setter and Zeller[31,32] have shown that in general an increase in the sulphate content of the sludge, if the accompanying anion is not a poison such as copper or zinc, will result in increased hydrogen sulphide production. O'Shaughnessy[20] suggests that the larger the proportion of water in contact with the digesting sludge the greater will be the likelihood of producing hydrogen sulphide. Thus, in his experience, gases from septic tanks are high in sulphides, those from Imhoff tanks frequently contain them, while they are rare in gases from separate digesters. A logical explanation of this phenomenon is that since the sulphates are mostly in solution the amount entering the digestion chamber varies directly with the moisture content of the sludge.

Not all the sulphur entering the digestion chamber is converted into hydrogen sulphide; some remains as free sulphur in suspension in the sludge. And not all of the hydrogen sulphide produced is evolved in the gas; some combines with the iron to form iron sulphide, that blackens the sludge; and some remains in solution in the sludge liquor.

Reaction.—Buswell[9] states that the gases formed during the early, acid phase of digestion frequently contain 25 to 50 per cent carbon dioxide; the quantity of methane is proportionately less, ranging from 50 to 65 per cent. This may be due in part to the fact that nitrogenous matter digests less rapidly at a low pH and hence the net result is somewhat similar to increasing the carbon to nitrogen ratio. During alkaline digestion part or

all of the hydrogen produced combines with part of the carbon dioxide to form water and additional methane. It is because of this reaction that the gas from properly digesting sludge contains little or no hydrogen while as much as 4 to 6 per cent of hydrogen may be present in the gas during the early stages of digestion. It also partially accounts for the increased methane and decreased carbon dioxide production during alkaline digestion.

Buswell[9] states that acid digestion favors the production of hydrogen sulphide in the gas because the increased concentration of hydrogen ions decreases the solubility of hydrogen sulphide and thus favors its ebullition. Bach[19] states that if decomposition takes place in an alkaline medium the hydrogen sulphide combines with ferrous hydroxide to form water and iron sulphide which remains in the sludge blackening it.

Completeness of Digestion.—Since the gases formed during the later stages of digestion are lower in carbon dioxide and hydrogen sulphide and higher in methane than those produced during the early stages, it follows that the more completely the sludge is digested the better will be the quality of the gas as regards both heating value and corrosiveness.

Temperature.—It is well known that heating increases the rate of gas production, but there are few data regarding the effect of temperature on the composition of the gas. Schlenz[21] states that variations in temperature up to 90° F. do not alter the composition of the gas, but P. J. A. Zeller in discussing Schlenz's paper stated that the carbon dioxide content was increased at higher temperatures. Buswell and Boruff[28] state that digestion of solids under thermophilic conditions, 131° F., produces no noticeable effect on the quality or quantity of gas produced in normally operating tanks. Rudolfs[23] states that the composition of the gas produced by thermophilic digestion is very similar to that produced under lower temperatures but that about 17 per cent more gas per pound of volatile matter is produced.

At Decatur[12] the hydrogen sulphide content of the gas was found to vary directly with the temperature of digestion, ranging from 0.3 per cent at 67° F. to 0.9 per cent at 75° F. The starch wastes sewage at Decatur contains very substantial quantities of sulphur dioxide, the decomposition of which is accelerated by the relatively high temperature of the wastes. The normal pH of the digesting sludge at Decatur is 6.8. Heilman and Korcher[11] state that at Halle, Germany, there appears to be more hydrogen sulphide in the gas during the summer than during the winter; it varies from 0.076 to 0.058 per cent. Sperry and Bachman[22] report the gas from thermophilic digestion to be high in hydrogen sulphide. Levine[22] also reports large quantities of hydrogen.

Disturbances.—Rudolfs *et al.*[24] concluded that the carbon dioxide content of the gas was a fairly good index of the state of digestion, and that digestion was not progressing satisfactorily when there was a marked

increase in the carbon dioxide content of the gas. It was found that this test could be used as an index of approaching trouble. Buswell,[9] Greeley and Hatfield[12] show that the carbon dioxide content of the gas is higher from foaming Imhoff tanks than from nonfoaming tanks. Donaldson[25] states that at New Castle the gas produced, though combustible, remained low in quantity until corrective treatment by liming was started. On changing the pH from a minimum of 5.1 to a controlled range between 7.3 and 7.6 the gas production was quickly accelerated some fifteenfold, accompanied by foaming. The carbon dioxide percentage during the transition stage reached a peak of 63 per cent and the gas was incombustible and odorous. As digestion proceeded the percentage of carbon dioxide gradually dropped to about 15 per cent. Since then it has ranged from 18.5 to 12.0 per cent. A. J. Fischer has told the writer that in his experience he has found the hydrogen sulphide content of the gas to be higher during disturbances of the digestion processes than when they were progressing satisfactorily, regardless of the cause of the disturbance.

Salinas Experiences and Experiments

Quality of the Gas.—The Salinas laboratory is not equipped to make gas analyses, but four complete analyses, shown in Table IV, have been made by commercial laboratories. Hydrogen, illuminants and carbon monoxide were absent from all four samples. The high oxygen content of these samples probably indicates dilution of the gas with air. In a previous discussion[4] of these analyses I stated the following:

> Apparently the digestion of activated sludge resulted in the prevention of hydrogen sulphide production; decreasing the hydrogen-ion concentration apparently had the same effect, but even at a pH of 7.2 there was a trace of H_2S when no activated sludge was being digested. If the air and hydrogen sulphide contents are omitted from the analyses and the methane and carbon dioxide quantities correspondingly increased, it will be seen that the digestion of activated sludge seemed to increase the production of carbon dioxide and to decrease the amount of methane produced; this effect was very pronounced at a pH of 6.8 but at a pH of 7.3 to 7.2 it was almost negligible. The analyses show that decreasing the hydrogen ion concentration results in decreased carbon dioxide formation and increased methane production.

These analyses indicated that the variations in methane content of the Salinas gas were no greater than would be expected and since, as the previous discussion shows, this variation would not be seriously detrimental to the performance of a gas engine no further complete analyses have been made. Therefore I have had no opportunity to check the above quoted statements relative to the effect of activated-sludge digestion and hydrogen-ion concentration on methane and carbon dioxide production. However, in view of the abnormally high hydrogen sulphide content of the gas in the first analysis and of the serious effect of this ingredient upon engine maintenance, "semi-quantitative" H_2S determinations have been made two to

four times weekly throughout the past year, using the apparatus shown in Figure 2. The determinations were made by exposing to a liter of gas strips of filter paper 22 × 77 mm. in size that were saturated with a 10 per cent solution of lead acetate. The work of the Bureau of Standards[26] shows that up to a certain limit the intensity of the brown coloration developed by the reaction of H_2S and excess dissolved lead acetate is proportional to the weight of H_2S per unit of area entering the reaction. They found that 0.005 milligram of hydrogen sulphide produced a faint brown coloration on 22 × 77 mm. papers; the upper limit used by them was 0.207 milligram. In a previous study[27] of the lead acetate test for hydrogen sulphide the Bureau of Standards found that the type of apparatus used materially effected the sensitiveness of the test. From their

TABLE IV

SALINAS DIGESTER GAS ANALYSES

	Date of Collecting Sample, 1931			
	Feb. 28	April 30	May 22	June 2
Cubic Feet of Gas Produced	6856	14224	8032	13070
Activated Sludge Digested Previously	No	Yes	No	Yes
Average Temp. of Digesting Sludge	62° F.	66° F.	68° F.	68° F.
Average pH of Digesting Sludge	6.8	6.8	7.2	7.3
Average Per Cent Solids in Digesting Sludge	6.7	5.8	6.1	5.0
Av. Per Cent Vol. Matter in Digesting Sludge	40.8	46.4	45.4	45.8
Percentage Composition by Volume:				
Carbon Dioxide	9.4	30.1	27.1	29.3
Methane	59.3	59.8	61.9	63.8
Nitrogen	11.2	8.9	9.6	6.4
Oxygen	1.7	1.2	1.4	0.5
Hydrogen Sulphide	18.4	None	Trace	None
Sulphur Dioxide	None	Trace	None	None
Calculated B. t. u. per Cubic Foot	723	603	624	645

work and from various determinations in which several different volumes of the same gas were tested, it is estimated that the adjectives used in describing the brown coloration roughly indicated the following percentages of hydrogen sulphide by volume in the gas: none 0.0004 or less; trace 0.005 to 0.0008; light 0.0015 to 0.0025; moderate 0.005 to 0.008; dark 0.015 or more.

The data accumulated in this work show: (1) No correlation between hydrogen sulphide production and the presence or absence of activated sludge in the daily charges of solids to the digester. (2) Variations in pH from 6.8 to 7.3 were certainly not the predominating factor in influencing hydrogen sulphide production. (3) There is at least as great if not a greater tendency to produce hydrogen sulphide at 60° F. as at 68° F. (4) The hydrogen sulphide production was more variable when the solid content of the digester was low; this may be due to the fact that there was

less digested sludge present to offset the variations in amount and character of the daily charges of green sludge. While these data offer little or no conclusive evidence as to the causes of variations in hydrogen sulphide production, they do show that it is entirely practical to so operate the Salinas digester that the gas produced will rarely if ever contain as much as 0.01 per cent hydrogen sulphide by volume.

Pipe Line Corrosion.—Soon after the Salinas plant was put into operation a gas line was laid from the plant to the operator's house, a distance of about 300 ft. The line consisted of used pipe varying from $1^1/_2$ to $^3/_4$ inches in diameter, laid without any attempt to grade it; therefore it had a few "ups and downs." The condensation trap in the gas collection system is very inefficient and considerable condensation took place in this line. Enough of the condensate could be blown out through a drain at the operator's house so that an adequate gas flow could be obtained, but it is probable that some condensate always remained in the dips of the line. After this line had been in service about two years it became increasingly difficult to get an adequate supply of gas through it and it finally became necessary to dig up the line. At the two lowest spots in the line the 1-inch pipe was found to be so completely plugged with a black scale that it was impossible to get more than a trickle of water through the pipe under 50 pounds pressure; the remainder of the line was practically free of corrosion. Analysis of the scale showed it to contain 59.65 per cent iron, 8.95 per cent sulphur and 7.63 per cent silica. The condensate removed from these spots contained an appreciable amount of sulphur present as sulphides and sulphates and also three groups of organisms as follows: (1) those capable of oxidizing free sulphur to sulphuric acid, (2) those capable of reducing sulphates to hydrogen sulphide, and (3) those capable of reducing sulphates to free sulphur. It seems probable that the black scale consisted chiefly of ferrous sulphide with some ferrous oxide. The fact that most of the line was comparatively free of corrosion shows that if the pipe lines are laid on self-draining grades and suitable means provided for frequently removing the condensate as it forms, the above reactions do not take place to a sufficient extent to become troublesome. If all the moisture, either vapor or droplets, could be removed from the gas there would be little bacterial life in the pipe lines and in addition ordinary rusting might be reduced because of the elimination of the carbonic acid.

Gas Engine Experiences.—In order to determine the effect of small amounts of hydrogen sulphide on an engine and to gain some first-hand information as to the difficulties to be expected in operating a gas engine a Model A Ford motor was operated on the gas during September, October and part of November, 1931. The motor was located in the open with no protection from frequent heavy fogs, and some rain, except a canvas. Although, as previously stated, it is desirable to increase the compression

of gasoline engines that are to be operated on gas this was not done; the only change made was to replace the carburetor with a gas mixing valve. No gas storage or pressure regulation was provided for and as the gas pressure varied from $1\frac{1}{2}$ to 5 inches of water this had a marked effect on the engine performance, as will be shown later. No adequate provision was made to condense and remove the water vapor from the gas. To load the motor a pump was provided, taking its suction from the wet well of the sewage pumping station and discharging into a manhole on the incoming sewer. During low sewage flows considerable difficulty was encountered in keeping the pump primed, so during most of the second run the motor was not loaded.

Two runs were made with this engine. During the first run the motor operated 272 hours and consumed 56,300 cu. ft. of gas. The hydrogen sulphide determinations showed no brown coloration of lead acetate paper 26 per cent of the time; a trace of coloration 64 per cent of the time and a light coloration 10 per cent of the time. During the second run the motor operated 320 hours consuming 33,700 cu. ft. of gas. There was no coloration of the lead acetate paper 23 per cent of the time; a trace 25 per cent of the time; a light coloration 29 per cent of the time and a moderate coloration 23 per cent of the time. After each run the engine was torn down and carefully inspected for corrosion. It was found to be in excellent condition in each case. The chief operating trouble encountered was in starting; it frequently required thirty minutes to get the engine running. It was very seldom that the engine could be started with the same adjustment of the mixing valve on which it had operated satisfactorily the day before. This may have been due in part to variations in the methane content of the gas, but the wide variations in gas pressure were probably the principal cause of the difficulty and exposure to the elements contributed also. The mixing valve used did not permit of very delicate adjustment and this complicated the problem. It is noteworthy that in spite of this difficulty the engine never stopped of its own accord once it was started.

Summary and Conclusions

A review of current literature and the experiences obtained at the Salinas, California, plant appear to justify the following conclusions relative to the effect of variations in the composition of sewage sludge digestion gas upon its utilization in internal combustion engines:

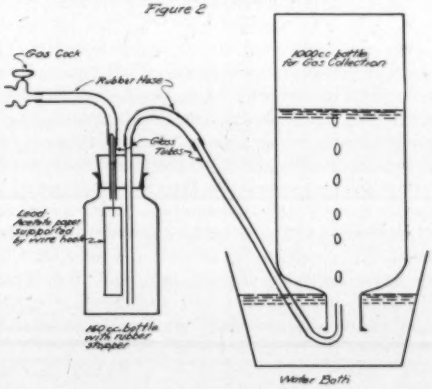
(1) The variations in the composition and heat value of digestion gas may be as great as those in the quantity of gas produced.

(2) The total heat value of the gas may range from 600 to 800 B. t. u. per cu. ft. but the heat value of the gas-air mixture utilized in an internal combustion engine will probably not vary more than 3 or 4 per cent and

hence the gas consumption per brake horsepower will be fairly uniform for a given engine loading.

(3) Methane, the principal combustible ingredient in sludge digestion gas, forms explosive mixtures with air through only a comparatively narrow range. And, further, since the methane content of the gas may vary from 60 to 80 per cent, frequent and careful adjustment of the gas-air mixture will be necessary to insure the most efficient engine operation.

ARRANGEMENT OF APPARATUS FOR HYDROGEN SULPHIDE DETERMINATIONS
Figure 2



(4) Although the amount of inert carbon dioxide and nitrogen in the gas may be comparatively high and subject to considerable variation, these gases constitute such a small proportion of the total volume of inert constituents in the actual gas-air mixture that the effect in retarding combustion is almost negligible.

(5) Carbon dioxide and nitrogen in the gas do reduce its explosive range, however, since they increase the minimum amount of air necessary for explosion more than they decrease the maximum amount. Although carbon dioxide reduces the explosive range slightly more than nitrogen, variations in the relative amounts of these ingredients are of little practical importance so long as their combined volume remains practically the same.

(6) The presence of small amounts of hydrogen, carbon monoxide or illuminants in sludge digestion gas has little effect on its power yield but may slightly widen its explosive range and so enhance its value as a motor fuel.

(7) Oxygen in the gas decreases the amount of air required for combus-

tion. The presence of more than 1 per cent of oxygen may indicate dilution of the gas with air.

(8) Sulphur compounds in a fuel produce serious corrosion because of the acid nature of their combustion products. Salinas experience shows that the presence of 0.01 per cent by volume of hydrogen sulphide causes no trouble and there is considerable evidence to show that a sludge digestion gas may contain as much as 0.07 to 0.1 per cent H_2S without being particularly harmful as an engine fuel. Due to the expense and difficulty of removing hydrogen sulphide from the comparatively small amount of gas produced by sludge digestion its use as a motor fuel will probably not be economically justified if it contains more than 0.1 per cent of that ingredient.

(9) Water vapor should be removed from the gas in so far as is practicable because it may cause large heat losses in the engine. If condensation takes place in the pipe lines it should be frequently and completely removed for it not only reduces the capacity of the lines but hastens their corrosion due to (*a*) the production of carbonic and hydrosulphuric acids by dissolving CO_2 and H_2S from the gas, and (*b*) the production of sulphuric acid by organisms that develop in the condensate. If the moisture in the gas originated as droplets of mist expelled by the ebullition of the gas it may contain sulphate salts in solution. If this moisture with its dissolved sulphates is not removed before reaching the engine the sulphates may be cracked by the high engine temperature and lose part of their sulphur, which will then be burnt, producing corrosive combustion products as harmful as those resulting from hydrogen sulphide.

(10) In general it appears probable that engines that have been designed to operate on natural gas will give almost as good results when utilizing sludge digestion gas. If gasoline engines are to be operated on the gas (or any other gaseous fuel) they should be equipped with high compression heads and even then they will develop 5 to 15 per cent less power than when operated on gasoline.

(11) Provision should be made for a stand-by fuel such as gasoline or butane gas for use during interruptions in the gas supply or periods of high H_2S production. The use of this fuel for starting may simplify operation. If gasoline is used as a stand-by fuel it should have an octane rating of 70 or better to avoid detonation at the high compression ratios required for gas operation.

(12) The engine should be protected from the elements, supplied with gas at a uniform pressure, and equipped with a delicately adjustable mixing valve.

(13) While much remains to be learned of the causes of variations in the composition of sludge digestion gas it appears that (*a*) a low carbon to nitrogen ratio and an alkaline reaction favor the production of methane

while the reverse conditions favor carbon dioxide production, and (*b*) an alkaline reaction reduces the tendency to produce hydrogen sulphide. Sudden changes in reaction or in amount or character of fresh solids may cause temporary increases in carbon dioxide and hydrogen sulphide production. Data on the effect of temperature upon the composition of the gas are meager and conflicting, but it appears that although temperature changes do not materially affect the proportions of carbon dioxide and methane in the gas, increases in temperature might tend to increase hydrogen sulphide production. Salinas experiences have not shown this to be the case.

(14) In general it appears that most of the factors that favor high methane and low carbon dioxide and hydrogen sulphide production are the same as those that favor the satisfactory functioning of digestion processes. Because of this fact, and because it appears that sufficient heat is available from the engine cooling water and exhaust gases to maintain adequate digestion temperatures, the utilization of the sludge digestion gas for power production is entirely compatible with the primary purpose of sludge digestion—namely, the conversion of the sewage solids to an inodorous, easily dried, residue. Whether or not the gas should be so utilized is merely a question in economics, the answer to which depends upon local conditions.

Under Salinas conditions, where electric power costs average about 1.2¢ per kilowatt hour, a careful study has shown that a properly designed gas utilization system would have a first cost considerably higher than an electric motor and control but even after deducting interest, depreciation and maintenance costs it would make an annual saving of 10 to 20 per cent of the additional investment. In spite of this fact it was decided not to install an internal combustion engine at this time and contracts have been recently let for installing an additional air blower driven by a 50-hp. electric motor and the conventional type of digester heating system. The reasons for this decision were: (1) The uncertainty as to the effect of increasing the digestion temperature to 80–90° F. upon hydrogen sulphide production. (2) The uncertainty as to the effect of the increase in temperature upon the amount of gas produced; there is some evidence that the Salinas sludge has not been completely digested in the past. (3) Increasing the air supply will increase the amount of sewage treated by the activated sludge process and hence the amount of excess activated sludge to be digested, but it is difficult to estimate just how much this will increase the total yield of gas. In order that the gas engine installation should make the greatest saving possible it is necessary that the engine be large enough to utilize nearly all of the gas produced, but the efficiency of the engine is greatly reduced if it is not operated at or near its full load. Thus, if the fuel consumption per brake horsepower when operating at full load is 1.00 it will range from

1.05 to 1.20 at $^3/_4$ load, 1.20 to 1.50 at $^1/_2$ load and 1.75 to 2.00 at $^1/_4$ load. It is therefore apparent that it is essential to know definitely the amount of gas available before selecting the size of engine to be used, if the greatest benefit is to be derived from the installation.

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The Rating of Sewage Disposal Plants According to Adequacy of Operating Data*

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The purpose of this paper is to stimulate interest in and to further the improvement of sewage plant operating data. The present situation is unsatisfactory for several reasons. First, there is a lack of knowledge on the part of many operators of the essential information and how to obtain it. This defect will be remedied in time through contacts with health representatives, schools for operators, improvement of personnel and growing activities of sewage works associations. A second reason is the deficiency at many plants with respect to sewage flow meters, weighing scales and even rudimentary laboratory equipment. The blame for this situation lies largely with the designing engineer who fails to provide the necessary equipment. There is seldom hesitancy on the part of municipal officials to add a few hundred dollars to the construction cost of a new plant in order to provide such facilities as may be recommended to give a satisfactory measurement of quantities and performance. After the bond issue is spent, however, and the plant goes on a budget allowance, how difficult it is to get a length of garden hose, a 40 watt light bulb or a garbage pail.

Illustrative of the lack of foresight in planning, the speaker recalls a visit, not long ago, to a plant designed for complete treatment of sewage. The operator was ambitious and anxious to carry out the simple tests for settleable solids and relative stability, but no space was provided in the plant for carrying out these tests, with the result that the operator was carrying his sewage samples into the kitchen of his near-by residence and making use of the kitchen sink for putting up tests and cleaning glassware. It may well be imagined that this arrangement was doomed to meet with a violent veto on the part of the outraged spouse, though no protest was noted on this particular occasion. It would have been a simple matter for the designing engineer, who expected these tests to be made, to have provided a small space in a gate chamber, with sink and water connection, a window shelf or table and a small cupboard.

A third reason for backwardness is the lack of sympathy of many municipal officials with record keeping in general and the failure to give even modest financial support and moral encouragement to an ambitious employee.

A fourth reason is the lack of a ready means of exchanging operating

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data and thereby making comparisons. Only a few of the larger cities publish annual departmental reports relating to operation of sewage treatment works, and in these lean years of pruned municipal budgets the number is likely to be much less. Sewage works associations are intended as a medium for exchange of operating experiences, but any one who has had the responsibility of getting up programs for these group meetings knows how difficult it is to secure papers on practical operation from the medium and small-sized communities. (EDITOR'S NOTE. Amen.)

An improvement in the situation both as to operating accomplishment and records is to be noted. The newer plants are provided with better equipment and the quality of operating personnel is improving. Operating forms are commonly used now-a-days. Some of these forms, elaborately printed on the best quality of ledger paper, with multicolored rulings, are quite out of keeping with the competence of the records inscribed thereon, but at least they are steps in the right direction. A common failing of plant records is that they are not systematically summarized and reduced to concise essentials, where the information would be helpful both locally and to others.

Through the efforts of committees of various technical societies and Federal and State agencies, attempts have been made from time to time to give proper direction to the reporting of sewage treatment data. For convenient reference a list of such reports is appended. The most recent effort in this direction is the report of a committee, headed by C. E. Keefer of Baltimore as Chairman, and made to the Federation of Sewage Works Associations, published in the January, 1932, issue of THIS JOURNAL. This report is constructively helpful in encouraging better record keeping and reporting of sewage data. Like most reports which attempt to cover a large field, it is possible that the Federation report by reason of its comprehensiveness may have tended to discourage the small plant operator from setting his house in order. It therefore seems to me to be desirable to discuss a classification of the essential operating data and to provide an incentive for carrying out the Federation committee recommendations. This classification is based upon my experience in dealing with typical operators of municipal sewage plants, and it takes into account limitations as to education, training and willingness to do certain tasks outside of the regular routine of managing the physical operations.

It is recognized that there are numerous plants throughout the country doing a very good job of sewage treatment without any records whatever of operation, conscientious application of common sense routine measures being sufficient to meet the situation. There is little hope of reaching the operators of such plants. This man will not attend association meetings and cannot or will not read any literature pertaining to sewage works.

So far as we are here concerned his plant is entitled to no rating. For other plants where operating data is available it is proposed to establish four classifications, as follows, in order of lowest to highest rating.

CLASS D. Plants with meager operating and test data.

CLASS C. Plants with limited laboratory equipment for weight determinations of sludge but not for sewage.

CLASS B. Plants with laboratory facilities for analyses of sewage as well as sludges and where fair cost data may be obtained.

CLASS A. Plants with ample laboratory equipment, operated under trained technical supervision and with good cost data available.

Before discussing the details of the several classifications attention is called to the descriptive data included in Schedule I of the Keefer committee report. No intelligent idea can be formed as to the adequacy of treatment of one plant compared to another unless one knows the nature of the treatment processes, the designed capacity and the connected population. One plant may do quite well during the first years of operation with an ample margin of capacity, while another plant for the same population might be continually in difficulties due to inadequate digestion space, sludge bed area, or other inadequacies. It will be noted that the information listed in Schedule I is made a requirement for all four classes of plants.

Class D Rating

It is suggested that a plant is entitled to a Class D rating if it systematically records the following data:

1. Descriptive data included in Schedule I.
2. Sewage flow, avg. max. and min. daily (metered).
3. Settleable solids, cc. per liter, 2 hr. influent and effluent (single daily sample).
4. Quantity of materials removed from sewage, cu. ft., and method of disposal.
5. Chemicals used in treatment, where applied and lb.
6. Gas production, cu. ft. daily.
7. Outdoor air temperature, max. and min.
8. Raw sewage temperature.
9. Relative stability of effluent.
10. Residual chlorine in effluent.
11. Days digested sludge is actually on drying beds, avg., max. and min.
12. No. dosings of sludge per bed each year.
13. Electric power, kw. hr.

There are obvious shortcomings in the data included in the above class. It may be complained that recording of temperatures or Imhoff cone tests, for instance, are relatively unimportant. Temperatures, however, do have bearing on sewage treatment, particularly on digestion and the thermometer is a cheap instrument which most any one can read reliably; the cone settling tests, in the absence of more exact data, do give a fair indication as to quality of raw sewage and the efficiency of tank treatment.

It is quite obvious, of course, that the number of cubic feet of material removed from sewage is a rather indefinite expression without knowledge as to the per cent of dry solids and the specific gravity. Screenings may have a quite variable water content, according to the manner in which they are handled in draining, and the fresh solids drawn from the underflow of mechanical settling units may vary from 0.5 to 8.0 per cent dry solids, according to the judgment used in operating.

At smaller plants where attendance is not provided both day and night, or where the operating personnel is limited, it is quite out of the question to collect composite samples of raw sewage and effluent. The usual practice of taking for the settling tests a single "catch" sample, usually in the morning, gives results which are admittedly not representative of the entire day's run. The same is true of the tests for relative stability and residual chlorine. These are all limitations which have to be accepted as inherent in this class.

The jump from Class D to the next higher Class C rating is not a great one. The operators of a Class D plant, if furnished necessary equipment and a little instruction, would be competent for Class C rating.

Good equipment for the drying, weighing and ignition of sludge samples and for other simple tests within the range of practicability for unskilled fingers costs between $150 and $200, and the use of this equipment adds considerably to knowledge regarding plant operation.

A good example of the value of sludge weighing is the New Haven plant, where sludge from Dorr settling tanks is barged to sea. It is rather important here to know that the sludge barge does not put out to sea with a load of dirty water instead of sludge solids. According to records in 1931, the dry solids as pumped from the settling tanks to storage tanks on the pier head averaged about 2.4 per cent. By repeated settling and decanting in the storage tanks, the sludge as loaded onto barge averaged about 13.5 per cent dry solids, resulting in a cargo each trip of some 31 tons, dry solids basis.

Class C Rating

Same requirements as Class D but with additions as follows:

1. Per cent dry solids in fresh sludge, digested sludge and sludge cake.
2. Per cent volatile solids in fresh sludge, digested sludge and sludge cake.
3. pH of sewage, fresh solids and digested sludge.
4. Temperature in digestion tank, avg., max. and min.
5. Sludge digestion space actually used, cu. ft.
6. Actual area in use of sludge drying beds or filters.
7. Average weight per cu. ft. of grit and screenings.

The data in Class C also have obvious limitations. Good information is available regarding sludge quality and condition, but no information

is available regarding sewage itself, except as to final effluent. The quality of raw sewage is not definitely known and the reduction brought about in sewage constituents by various steps is left unanswered. The reason for this is that the average Class C operator is usually lacking the skill necessary in weighing on the delicate analytical balance and in carrying out other laboratory observations which call for the training of a chemist.

Moving up to the next higher class, Class B, implies the possession of additional laboratory facilities suitable for making the more important tests on sewage itself. Such additional equipment comprising analytical balance, Gooch crucibles, colorimetric sets, glassware, etc., need not cost more than $200, exclusive of furniture such as tables, cabinets, or desks. This classification also implies that the operator has received a technician's training equivalent to that obtainable in some of the State short courses. It also implies that the operator has a certain amount of resourcefulness in assembling reliable cost data. Costs are notoriously difficult to obtain, due principally to the accounting being in a separate municipal department.

Class B Rating

Same requirements as in Class C with the following additions:

1. Suspended solids in screened sewage, tank effluent and final effluent.
2. B. O. D. test of screened sewage, tank effluent, filter effluent and final effluent.
3. Cost of plant, plus improvements to date.
   - (*a*) Land.
   - (*b*) Treatment Works.
4. Operating costs.
   - (*a*) Outside supervision.
   - (*b*) Salaried employees.
   - (*c*) Day labor, regular and extra.
   - (*d*) Chemicals used in treatment.
   - (*e*) Power.
   - (*f*) Light.
   - (*g*) Fuel.
   - (*h*) Water.
   - (*i*) Telephone.
   - (*j*) Miscellaneous supplies.
5. Total power used, kw. hr., separated as
   - (*a*) Power required for pumping sewage.
   - (*b*) Power required in treatment proper.

The next higher classification, Class A, implies that the plant is managed under skilled engineering and laboratory supervision and that facilities are at hand for all measurements and determinations called for in the full schedules of the Federation report, including reliable segregated cost data and fixed charges. Only a few plants for the larger cities can be expected to attain this rating.

The above classifications as set up are not insisted upon as being final, in fact it is anticipated that they will require modification.

The next step in this proposal is to set up some system by which an incentive would be furnished to plant operators and municipal officials to secure a good rating. The situation here is analogous to the reporting of vital statistics whereby little beginnings may grow into something worth while.

The systematic reporting of deaths and births in the United States was started in 1880 by the formation of a registration area comprising only the states of Massachusetts and New Jersey and the District of Columbia, which area comprised only 0.6 per cent of the total area and 17 per cent of the total population. By 1908 the registration area had been extended to cover 16 additional states, comprising 24 per cent of the total area and 53 per cent of the total population. By 1928 the registration area comprised 81 per cent of the total and 95 per cent of the total population, including 44 states, Hawaii and the Virgin Islands. At the present time Texas and South Dakota are the only states not in the registration area, although the principal cities of the two states are included. Porto Rico and Alaska are included.

The simple requirement of admission to the registration area is the ability to report systematically to the Census Bureau at least 90 per cent of the deaths and births.

In those states which require systematic reporting of sewage plant operation the State Board of Health is undoubtedly in position to assign to plants within the state their proper class rating. The State Board of Health Organization, however, is already much burdened with important duties and moreover there are some areas containing important sewage works where compulsory reports are not forwarded to the State Board of Health. It is believed better, therefore, to have the matter of plant rating taken care of by the fraternity with the coöperation of the State Health Department. The Federation of Sewage Works Associations as now constituted has no machinery for this kind of executive work. It is suggested, therefore, that the local associations making up the Federation each appoint a standing committee, one member of which shall be a representative of the State Board of Health or representatives of the several State Boards of Health. This committee would have the responsibility of establishing class rating upon submission to it of evidence in the form of printed reports, manuscript reports, or published articles that various requirements have been complied with. A report of this certification committee should be made at each annual meeting of the local association and copy should be furnished to the Federation editor for publication annually in the JOURNAL.

In offering the above proposal the speaker is acting in no official ca-

pacity. He wishes to acknowledge the helpfulness of suggestions received from Messrs. Paul Molitor, Sr., A. L. Fales, L. H. Enslow, C. A. Holmquist and C. E. Emmerson, Jr., in discussions on this subject, although he imputes to none of these gentlemen responsibility for the views herein set forth.

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A Contribution to the Design of Grit Chambers

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TRANSLATED BY G. P. EDWARDS

The following formula is now generally used in calculating the dimensions of grit chambers:

$$\text{Cross-section (sq. ft.)} = \frac{\text{flow (cu. ft./sec.)}}{\text{velocity (ft./sec.)}}$$

The length of grit chambers, which must be determined according to the judgment of the designer, depends on the amount of sand to be collected. The longer the grit chamber, the greater the certainty that no sand will pass over into the plant and also the greater the danger that deposits of sludge will occur in the outlet end of the grit chamber. This sludge can be removed by blowing in air or by mechanical means. The comparatively long, shallow grit chambers usually built in Germany require a considerable amount of apparatus which has not been generally used. One of the reasons why such apparatus has not been used more widely is because its action is effective only directly over the aeration equipment and the rest of the sludge deposit remains untouched.

For systematic operation two to three compartments, alternating in operation, are required. Since the deposit of grit usually reaches a depth of only 12 to 15 inches, mechanical removal equipment is not worth while. Under the individual compartments are placed drainage systems which may be used for draining the sand when the chambers are taken out of operation. Grit is usually removed by hand. The difficulty in such grit chambers is that velocities change greatly with fluctuations in flow. The flow varies from hour to hour during the day and even more from dry to wet weather. If a second or third grit chamber should be needed for an exceptionally large flow, sludge deposits result which not only render the grit unfit for use, but even make its disposal difficult because of odor trouble. In many cases the erection of a grit chamber has been dispensed with, especially in two-stage plants, in which equipment may be used to remove the grit with the sludge.[1] The vertical removal of the sludge and grit mixture by means of compressed air offers no difficulties. If this mixture flows through a pipe by gravity deposits tend to form and even stoppage of the pipe may result. To avoid this difficulty a large amount of water with high velocities must be used in long horizontal sludge lines.

In his report on grit chambers in 1926, H. C. H. Shenton[2] came to the conclusion that, in general, grit chambers proved to be only collection tanks for large amounts of organic sludge and he recommended that

engineers earnestly turn their attention to the design of a successful grit chamber. He referred to a paper published in the *Transactions of the American Society of Civil Engineers*[3] under the title "Use of Grit Chambers: A Symposium" with discussion by George B. Gascoigne, F. Y. Dallyn, K. Imhoff and Arthur J. Martin. All the authors agreed as to the importance and the need for improvement of grit chambers. It was brought out that most engineers have used tank types. It was also stated that

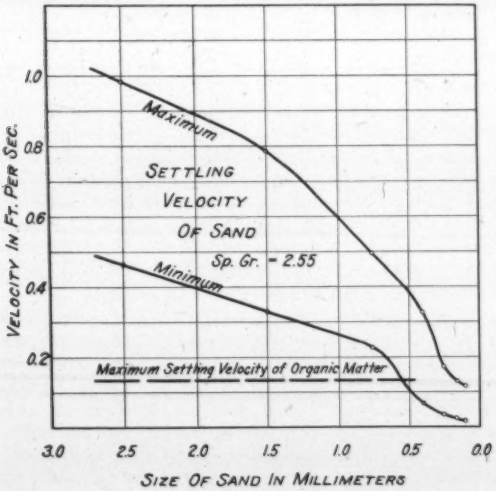

FIG. 1.—Settling Velocities of Rhine Sand of Various Sizes with a Specific Gravity of 2.55. The Greatest Settling Velocity of Organic Solids Is Shown (Sludge-Forming Solids). (Whole Pieces of Potatoes and the Like May Have Greater Velocities.)

in Germany the cross-section of a grit chamber is designed to maintain a velocity of 1 ft. per second.

The opinion seems to prevail that general principles cannot be laid down for the calculations and dimensions of grit chambers, since the conditions in the individual cities vary so greatly.

Grit chambers with hopper bottoms have not proved satisfactory because sludge collected in the deepest part soon becomes septic.

Several types of grit chambers have been described which require considerably greater horizontal velocities in order to obtain grit which is usable.

Ehnert[4] of Dresden, in his experiments on the removal of grit from municipal sewage, came to the conclusion that the average velocity of 1 ft. per sec. can be used as a basis for calculation only for certain conditions. He recommended that, in every case, the motion of the particles be determined by experiment.

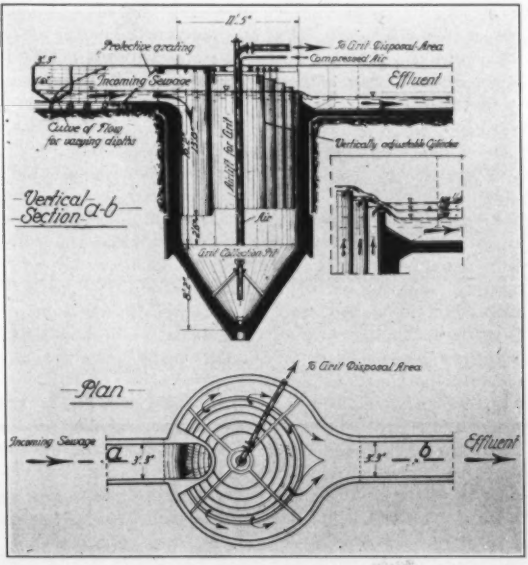

FIG. 2.—Design of a Grit Chamber with Five Compartments Which Are Brought into Operation Consecutively with Increasing Flow by Means of Varying Outfall Weirs, and Are Automatically Cut Out of Service with Decreasing Flow.

Every sanitary engineer knows that, in flows free from eddies, at a velocity of 1 ft. per sec. the sewage solids are in the act of settling and will be deposited if there is a long enough stretch of uniform flow, that is, if the solid material can reach the bottom before it is caught up again by the turbulence caused by change of direction. Consequently, there must be a definite relation between the length of the tank and its depth. A certain period of time is also required before the water in the grit chamber flows without a swirling motion and the settling action can begin.

The settling velocities of the individual sludge particles and the water depths determine whether or not the particles will reach the bottom. Once deposited, the transporting power of the water in the grit chamber is no longer sufficient to pick up the gravel and sand masses at the bottom. They will be deposited and remain near the inlet of the chamber.

Practice has shown that the determination of the dimensions of a horizontal-flow grit chamber is extraordinarily difficult and uncertain. The use of upward-flow motion of the water makes possible a clearer and more certain basis of calculation, because the only two forces which must be considered can be accurately determined beforehand. One force is the upward velocity, which can be determined by choosing the proper cross-section of flow. The other is the force of gravity, which affects the settling velocity of the individual particle. All particles which have a settling velocity less than the upward velocity cannot sink to the bottom, but are carried away with the flowing water; only that material whose settling velocity is greater than the velocity of flow sinks to the bottom and separates from the remainder of the suspended material.

In the design of such a grit chamber it may be determined beforehand to what extent the sand particles will be retained. The practical limit is reached when the suspended organic material has the same settling velocity as the smallest particles of mineral matter. If it is desirable to retain the finest mineral particles then the equally heavy organic solids will sink to the bottom.

Only those solids should be retained in the grit chamber which interfere with further treatment. Suspended solids so fine that they act like silt interfere neither with sludge digestion nor transportation. In general, all solids with a diameter less than 0.5 mm. can be neglected.

In order to determine the settling velocity, experiments were carried on with different sizes of Rhine sand. The results were as follows:

Size	Settling Velocity	
	Highest, Ft. per Sec.	Lowest, Ft. per Sec.
Under 0.15 mm.	0.11	0.015
From 0.15–0.2	0.14	0.028
0.2 –0.28	0.18	0.037
0.28–0.5	0.33	0.075
0.5 –1.0	0.50	0.222
1.0 –2.0	0.78	0.318
Over 2.0	0.98	0.465

The specific gravity of the sand was 2.55. The values found are shown graphically in Figure 1.

An approximate idea of what will be retained in the grit chamber with different water velocities can be obtained if a horizontal line is drawn through the chosen velocity. Theoretically all that lies below this line

is washed out by the upward velocity of the water. This would be correct if the water motion could be determined as accurately in practice as it is in theory. Since unequal flows will always adjust themselves to a certain degree, it is usually found that more is retained than indicated by the diagram.

Experiments were carried on, using different sizes of sand and different velocities, to determine the amounts of sand washed out at given vertical velocities. Definite amounts of sand of definite sizes were added to a water-filled cylinder 23.6 inches high and 3.9 inches in diameter. After all particles had settled to the bottom, water was passed up through the cylinder at different velocities for 2-hour periods. Results are shown in Table I.

TABLE I

EFFECT OF VELOCITY AND SIZE ON THE ELUTRIATION OF SAND

Velocity of Water, Ft./Sec.	Size of Sand						
	Over 2 mm.	1–2 mm.	0.5–1 mm.	0.28–0.5 mm.	0.2–0.28 mm.	0.15–0.2 mm.	Under 0.15 mm.
	Per Cent Washed Out						
0.033	None	None	None	None	None	3.3	17.3
0.066	None	None	None	None	8.5	21.7	92.7
0.098	None	None	None	24.9	59.0	98.0	100.0
0.131	None	None	None	34.4	64.0	100.0	
0.164	None	None	None	37.6	68.0		
0.197	None	None	None	45.0	72.0		
0.230	None	None	Trace				
0.262	None	None	5				

It may be inferred from these results that the finest particles of the sand (under 0.15 mm.) were completely washed out in the stated time with an upward water velocity of 0.098 ft. per sec., although the settling velocity varied by ±0.017 ft. per sec. between 0.098 and 0.131 ft. per second. With a velocity of 0.033 ft. per sec. the removal was only 17.3 per cent. With a size of 0.28 to 0.50 mm. the highest settling velocity was 0.33 ft. per sec. and the lowest 0.075 ft. per second. With an upward velocity of 0.098 ft. per sec., 25 per cent of the material was carried off. These observations were confirmed when a size of 0.5 to 1.0 mm. was used. The settling velocity varied between 0.22 and 0.50 ft. per second. With a water velocity of 0.23 ft. per sec. traces of the material began to be washed out, while there were no losses with lower velocities. In this way it is comparatively simple to determine in advance what size of sand particles will be retained in the grit chamber.

The results of experiments on about 100 samples of different kinds showed that the greatest settling velocity of organic matter lies at about 0.098–0.131 ft. per second. If the water in a grit chamber has an upward velocity of about 0.197 ft. per sec. it is reasonable to expect that the

organic matter would pass through the grit chamber with the sewage, but sand of size up to 0.28 or 0.5 mm. would, for the most part, be retained (all solids which lie above a horizontal line drawn through the 0.197 ft. per sec. velocity).

Since the sewage flow varies from day to day, especially during stormy weather, and since nearly constant water velocity must be maintained,

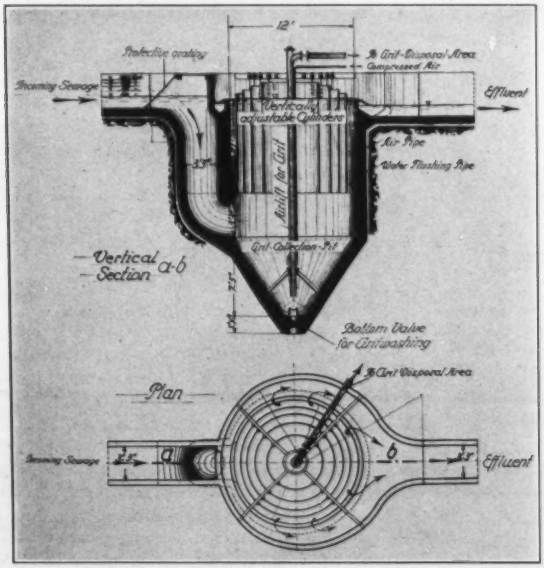

FIG. 3.—The Same as Fig. 2, Except the Influent Is Built as a Siphon Outside the Chamber.

several compartments must be available for removal of grit if uniformly clean grit is to be obtained. The size of the compartments should be adjustable to the prevailing conditions. The cross-section for the one compartment which always remains in operation is calculated for the minimum flow. The difference between the minimum and maximum flow can be subdivided in any desired way. The different compartments are suitably fitted into one another, beginning from the outside with the minimum flow or the reverse. The sewage is led through a vertical pipe

down into a tank and then vertically upward through the different grit chambers, which have been provided according to the variation of flow.

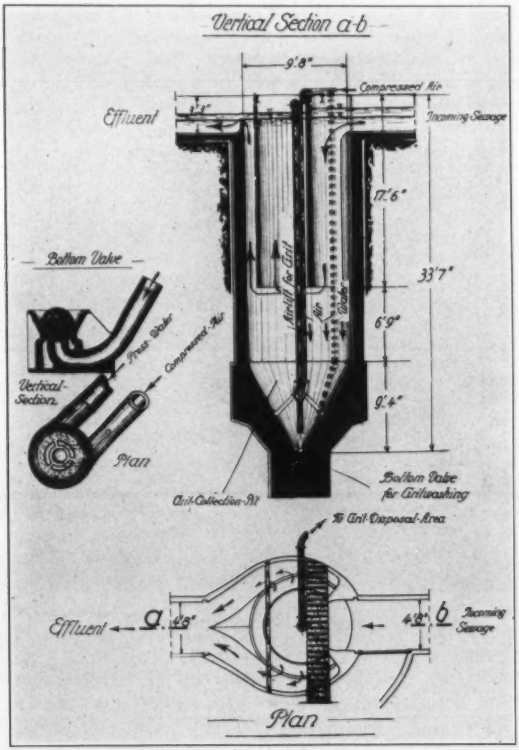

FIG. 4.—Grit Chamber at the Bochum Plant. The Upper Part Is the Multiple-Compartment Separator. Stilling of the Flow Occurs in the Center. At the Bottom Is the Grit-Collecting Sump, Below Which Are the Valves and Inlets for Water and Air.

The compartment for minimum flow has the lowest overflow weir. The overflow weirs of the remaining wells are higher and the height depends upon the overflow curve of the inlet and outlet channels (Figure 2). At

low level the sewage flows only through the compartment designed for it, since it has the least resistance. If the flow increases, the water level of the influent and the effluent rises, the cross-section of the grit chamber is no longer sufficient for the existing increased head and the second and third compartments go into action according to the increase of the volume of sewage (maintaining a constant velocity). With a decrease in flow one compartment after the other cuts out of service. The elevation of the different overflow weirs can be accurately determined in accordance

FIG. 5.—Grit Chamber at the Bochum Plant (180,000 Population), with Vertical Flow. Several Compartments Are Shown with Overflow Weirs at Various Elevations.

with the head in the influent channel, in connection with which the head loss inside the grit chamber must be taken into consideration. With medium-sized plants this amounts to only a few inches. In order to keep a free overflow the bottom of the effluent channel is set a few inches lower.

There is a common grit storage space under all the wells. The bottom of this compartment slopes steeply so that the grit slides down into the sump, from which it is to be removed (Figure 3). In the simplest case the grit is raised by aid of compressed air, as is customary in other plants. But in these plants it often happens (especially with greater accumulation

of grit) that sufficient water cannnot flow down through the grit to enable it to be moved. When this occurs the compressed air escapes through the voids without raising the grit. It is therefore necessary that water be added from below with the compressed air so that the grit will be carried along in the air-water mixture. At the deepest part of the chamber there is a common point of discharge for air and water, which, when not in use, is closed by a valve (ball or globe) (Figure 4). If the grit becomes packed, air and water are blown in through the pipe under great pressure, either at the same time or one after the other. If there is enough pressure the valve is opened and the air and water can escape upward. The grit deposited in the lower part of the chamber is put into suspension by jolts of injected water and, in this way, is washed. When the air lift is first put into operation the grit is forced out with a part of the water. The water raised with it separates from the grit and flows back into the influent channel.

If a minimum flow of 7.1 cu. ft. per sec. and a maximum of 35.4 c. f. s. are assumed, the following factors must be taken into account: The minimum settling velocity of the particles which should be retained under all circumstances is 0.36 ft. per second. The upward velocity of flow can therefore amount to 0.328 ft. per second. Accordingly, the cross-section for the minimum flow is

$$A_1 = \frac{Q}{V} = \frac{7.1}{0.328} = 21.4 \text{ sq. ft.}$$

For the maximum

$$A_2 = \frac{35.4}{0.328} = 108 \text{ sq. ft.}$$

If five compartments are provided it is possible to make an accurate adjustment to the various rates of flow. The influent channel is designed for the maximum flow. In order to obtain the least possible loss of head inside the grit chamber the inlet channel has a diameter of 3 feet. According to the foundation conditions, the channel can either be led in from the outside, as an inverted siphon, or arranged inside the tank (Figures 2 and 3). In the latter case the different compartments are arranged concentrically or eccentrically around the influent channel (Figure 2). The sewage is led down through the middle of the grit chamber with a velocity of about 3 ft. per second. The pipe curves at the point of introduction. In this way a circulating motion is developed, which tends to diminish velocity, so that the sewage acquires the desired decreased velocity as soon as it turns upward. A distance of about 10 feet is usually sufficient for the upward path of the water. The depth of the storage space depends upon the diameter and the slope of the bottom and is consequently greatest in large installations. In order to avoid great depths when large amounts of sewage are treated, the use of two or

even three grit chambers in parallel is recommended. Nevertheless, when ground conditions are favorable tanks can be built to a depth of about 33 feet. The plant shown in Figures 2 and 3 is adequate for the assumed conditions.

FIG. 6.—Grit Chamber at the Bochum Plant. View from Above Into the Central Compartment 33 Feet Deep. The Concrete Wall in the Background Is the Inlet Conduit, Which Introduces the Sewage Halfway Down the Chamber. In Front of This Conduit Is Shown the Air Lift, through Which the Grit Is Removed. The Walls of the Chambers Are Made of Wood, and Are Adjustable from Above.

The grit chamber in the Bochum treatment plant, shown in Figures 4, 5 and 6, was built according to these principles of design. The minimum flow is 13.8 c. f. s. and the maximum 35.3 c. f. s. Under these special conditions it was intended, from the beginning, only to retain that grit

which would interfere with the transportation of the digested sludge, that is, solids which exceed 1 mm. in size. Therefore, a velocity of 0.59 ft. per sec. was chosen. The cross-sections were determined as follows:

$$A_1 = \frac{Q}{V} = \frac{13.8}{0.59} = 23.4 \text{ sq. ft.} \qquad A_2 = \frac{21.5}{0.59} = 36.4 \text{ sq. ft.}$$

The depth of the grit chamber is 15.9 feet and that of the storage space underneath 14.6 feet. These depths resulted from a consideration of the

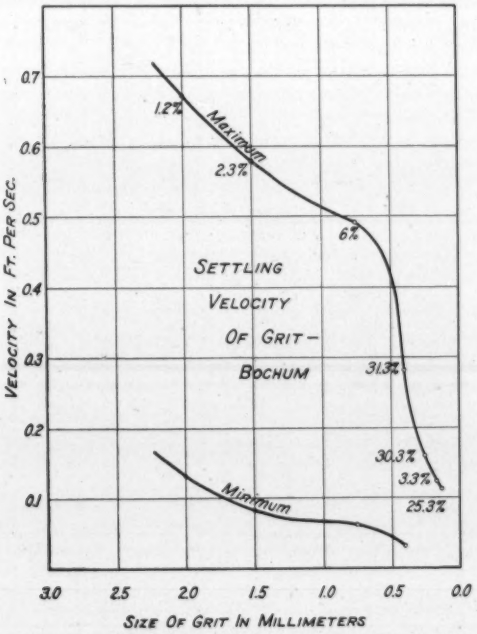

FIG. 7.—Classification of the Grit Removed from the Grit Chamber at Bochum.

diameter of the grit chamber, the necessary slope of the bottom and the desired capacity. The storage space for grit is 600 cu. feet. In dry weather the capacity is sufficient for 14 days and in ordinary rainy weather for 1 day. Under unusual conditions, heavy showers, for example, the

grit must be removed during the high water. This is extremely simple and may be accomplished in a short time.

Since, as has already been mentioned, the sewage circulates, to a certain extent, in the deep grit storage compartment when it is not filled with grit and a part of the sewage can be retained there for a short time, it is always possible that traces of sludge can be deposited with the sand. If completely washed sand is desired it is necessary only to force a water-air mixture into the compartment from the deepest point of the grit chamber for a few seconds. In this way the contents of the storage compartment are raised into the zone of flow where a separation, according to its settling velocity, results. The sand particles sink to the bottom, whereas the organic matter which is retained in the storage compartment, only because of the decreased velocity, passes with the sewage to the clarification plant.

As soon as the washing is completed the air is turned off and the grit flows, with a certain amount of water, through the pressure pipe to the storage area (Figure 8), where it is dried in a few minutes. The water is returned to the inlet of the grit chamber.

The Bochum plant has been in operation for some time. The solids obtained have been analyzed many times. The results of ten determinations show that these samples contained:

Water	4.22%
Dry material	95.78%

and the dry material contained:

Mineral matter	98.04%
Organic matter	1.96%

The collected and dried material was sieved and the distribution, according to size, was as follows:

Over 2 mm.	2.72%
From 1.0 –2.0 mm.	25.28%
0.8 –1.0 mm.	38.68%
0.28–0.50 mm.	30.58%
0.2 –0.28 mm.	1.56%
0.15–0.2 mm.	0.06%
Under 0.15 mm.	1.0 %

The sieve loss was 0.12 per cent. The sieve tests of the ignited material gave similar results.

From these results it may be seen that the grit chamber fulfils its purpose. The material obtained is practically free from organic matter even though solids less than 0.5 mm. in diameter are retained. The smaller sizes can be neglected. The coarser materials were removed prior to analysis, since obviously they would be eliminated from the sewage

because of their higher settling velocity. The amount of this material is dependent on local conditions. As a check on the action of the grit chamber the velocity in the effluent channel was reduced and the bottom sludge thus obtained was analyzed. It was found that of the mineral matter in the sludge, only 1.2% was of 2 mm. size, 2.3% of 1.5 mm. size and 6% of 0.75 mm. size. The largest amount, that is, about 90% was 0.2–0.4 mm. in size and had a settling velocity of 0.033 to 0.262 ft. per second (Figure 7). These control experiments confirmed the fact that the grit chamber had solved the problem of retaining the sand over 1 mm. in size.

The cost of such a grit chamber is less than that of a shallow grit

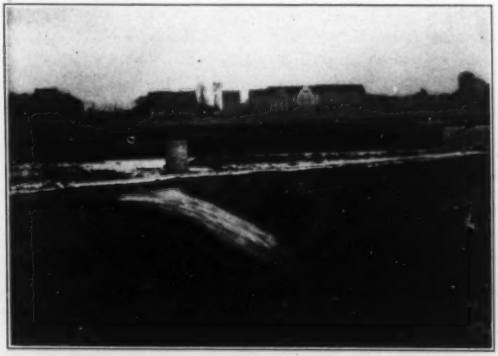

FIG. 8.—The Grit Is Blown Out with the Aid of Compressed Air.

chamber. The operation is extremely simple and there is no operating cost except for the compressed air used from 10–15 minutes daily. It is ready for operation under all conditions for which it was planned, without sludge removal equipment and without special servicing. The material obtained can be dumped anywhere without being objectionable or can be used for filling in land.

Summary

The well-known shallow grit chamber cannot easily be adjusted to widely varying rates of sewage flow. Putrescible sludge as well as sand is frequently retained. The basic principles have been given herein for the design of grit chambers of the upward-flow type. The advantages of this type of grit chamber have been stated and it has been shown that

it is possible to take into consideration from preliminary investigations the properties of the material to be handled and the rates of sewage flow.

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Industrial Wastes and Stream Pollution

The Industrial Waste Problem in Sanitation*

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The sanitary significance of the industrial wastes problem lies in the fact that many such wastes create health hazards by seriously polluting our streams, lakes and harbors. Many industrial wastes are destructive to sewerage systems and interfere with processes of sewage treatment which are largely biological in character.

Pollution of streams and lakes by wastes from industrial processes has been recognized for many years. Man, however, was tolerant, because manufacturing plants were few and far between and he was not compelled to live in proximity to them. Many of the present-day uses of streams were unrecognized and indeed unnecessary. The modern municipality and industrial area did not exist.

In the latter part of the eighteenth century the first industrial charters for the development of manufacturing industries were being sought. The creation and development of communities necessitated the transfer of domestic sewage from an objectionable concentration of individual privies to a water carriage system leading to the nearest watercourse. This necessity was mother of Sir John Harrington's invention of the water closet in England early in the 19th century.

Industry makes extensive use of surface water for power, processing, transportation and waste removal. Frequently, contiguous urban developments require and are entitled to use of the same source of water for drinking, sewage disposal and recreation. In large industrial areas the growth of these demands upon surface waters has developed rapidly and is in many instances overtaxing the assimilative capacities of many of the largest watercourses.

The necessity of removing pathogenic organisms, unsightly floating solids, grease, etc., common to domestic sewage, from nearby streams by adequate treatment received early recognition. Although the bulk of domestic sewage is still untreated the larger municipalities of the world

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have provided some degree of treatment for domestic sewage, thus taking the initial step in stream conservation.

With the exception of a relatively few highly poisonous gaseous and liquid chemical discharges from industrial processes the pollution of watercourses by untreated domestic sewage is more repulsive and potentially more dangerous to the health of a community than the pollution created by the average industrial waste. For this reason the domestic sewage problem probably received earlier recognition. The science of sewage treatment is developing rapidly. The fundamental principles involved in sewage treatment and stream protection are being disclosed by intensive research. Standards of stream cleanliness are being developed and studies of the relationship of the more intricate waste discharges from industrial processes to these standards are among the more recent developments in sanitation. Attempts are being made to evaluate the character and strength of the many types of industrial wastes in terms of domestic sewage and its population equivalent. Likewise efforts are being made to determine separate methods and costs of treatment for various wastes required to convert them into discharges that will not impose excessive burden on local streams, destroy community sewer systems or seriously affect local sewage treatment processes.

Strictly domestic sewage is rather uniform in quality and strength, whereas industrial wastes vary widely in character. Certain general subdivisions, however, are practical. For liquid discharges the broad subdivision is probably organic and inorganic material. Their effects upon streams, sewer systems and sewage treatment processes are varied, indeed, and it is the intricate liquid industrial wastes problem that confronts the modern sanitary engineer, since it complicates his methods of water purification, sewage treatment and stream conservation.

Other uses of streams exacted by transportation, commerce and power development are largely economical in character. Such stream assets, nevertheless, are of inestimable value to the life of a community and must be equably reckoned with in any program of stream evaluation and conservation.

Heavy solid industrial wastes, such as saw dust, slag, etc., occasionally offer less serious problems to the sanitarian. These are more or less strictly local and usually have little if any effect upon the community.

Within the last decade, but more especially during the past four years, the interest of public health engineers in the developing exigency for stream cleanliness and conservation has extended to more intensive consideration of the industrial waste problem. The major activities in this field have been initiated by State Departments of Health through bureaus of sanitary engineering or sanitation. Various types of national state and interstate administrative agencies have either been established or are in process of

organization. Recourse to mere enforcement of common law, prohibition of discharge and efforts to subject all waste discharges to a universal form of treatment were earlier expedients that have met with failure.

In 1930 H. Maclean Wilson,[1] former Chief Engineer, West Riding of Yorkshire River Boards, England, outlined repeated failures of early official actions in England in the direction of prevention of stream pollution and the recently improved methods which now provide reasonable flexibility in the determination and control of causes, effects and changes in industrial and domestic wastes in streams. England's present method provides continuing administrative bodies equipped with scientific personnel to control entire river drainage areas and to evaluate and regulate on the basis of scientific facts.

Today various forms of administrative control are developing in America. Each is governed more or less by the nature of local problems. A résumé of the legislation, restrictive or regulatory, promulgated by the various states forms part of an enlightening symposium[2] on American practice presented by *Chemical and Metallurgical Engineering*.

In the fall of 1931 the Chemical Section of the National Safety Council discussed the health hazards and property damage resulting from inadequate waste disposal. Shortly thereafter the American Institute of Chemical Engineers held a symposium at their 24th annual meeting on stream pollution and industrial wastes. Coöperating with committees of the American Engineering Council such organizations as the Technical Association of the Pulp and Paper Industry and the American Petroleum Institute have developed programs of scientific research that should rapidly solve their specific problems. Additional coöperation by other individual industries is under way.

Interstate agreements exemplified by the Ohio River and Great Lakes Boards of Engineers are coördinating scientific research and regulatory procedures. A joint committee of these two boards has recently standardized procedures for the determination of biochemical oxygen demand. (See THIS JOURNAL, p. 738 (Sept., 1932).) The application of these procedures to the variety of industrial wastes is the present intricate problem now before this committee. The Conference of State Sanitary Engineers has recently been solicited by the American Petroleum Institute to coöperate in a study of wastes from the oil industry. It is obvious that sanitarians have adopted sound policies and scientific procedures. This is attracting the necessary support of organized industries and scientific groups.

The industrial waste problem in Maryland has been under persistent fire for the past fifteen years. With the assistance of the inspection service of the Conservation Commission, the State Department of Health through its Bureau of Sanitary Engineering has dealt patiently with the officials

of a variety of industries and supplied much experimental field, laboratory and pilot plant data that have developed waste treatment processes now considered essential to efficient plant operation. The small amount of industrial wastes entering the sanitary sewers of Baltimore has caused little, if any, trouble in the sewer system or at the disposal plant. Pollution from the larger industries of this city, which was concentrated in the waters of Curtis Bay and Baltimore Harbor, was eliminated within the period of a few years after the World War, during which local atmospheric and stream pollution was tolerated because of the emergency then existing. Another group of industrial plants located on the Upper Potomac River above the City of Cumberland was likewise left undisturbed during the war period. The practice of indiscriminate and extravagant waste of valuable products which developed during this period in industrial areas throughout the world was exemplified at these two points in Maryland. A policy of reasonable tolerance was adopted and the Engineering Bureau was supplied with chemically trained personnel experienced in sanitation problems.

In the Curtis Bay and Baltimore Harbor area there were waste discharges from various industries including a tannery, an alcohol distillery, sulphuric acid works, fertilizer and organic chemical works, paint pigments works, steel rolling mills and oil refineries. The section is highly industrialized and located upon several tributaries of Chesapeake Bay near Baltimore where shipping facilities are attractive. The waters are tidal, but due to the small amount of fresh water entering them and a relatively small change in volume of diluting water through the tidal prism, the large volumes of putrescent and acid wastes produced objectionable conditions resulting in complaints from excursionists, residents, shippers and fishermen. The combined pollution caused heavy fish mortalities, boiler and condenser troubles and decolorization of the paint on boats.

Investigation of conditions in this area began in 1915. Shortly after the World War the Director of Health called representatives of the various industrial plants and Baltimore health officials into conference. Under the leadership of the Chief Engineer of the State Department of Health a program was developed to investigate the condition of the waters, the individual manufacturing operations and the volume and character of their waste discharges. The salvage of manufactured products by improvements in operation and the development of by-products paid much of the way to improvement.

The heavier demands upon the adjacent water area were in the vicinity of the alcohol distillery and the tannery. The remaining areas exhibited less objectionable forms of pollution due to relatively smaller volumes of acid and oil. Corrections advocated by the group investigation were adopted without legal pressure and a remarkable cleanup was obtained.

The usual hair, fleshing, tanning and lime wastes from the tannery which, combined, had an average 5-day, 20° C. biochemical oxygen demand about twenty times that of domestic sewage were screened and settled in a Dorr Clarifier. Wastes from the screening pit were removed by a bucket elevator. Sand beds were constructed for drying the sludge. The sludge was to have been used to reclaim low, swampy ground. A number of difficulties were encountered and the treatment, though improving the quality of the discharge, was not finally approved by the State Health Department. Sludge is now satisfactorily lagooned but the Dorr clarifier effluent is highly colored and further treatment is desirable. There have been notable improvements in treatment processes for tannery wastes. A bulletin published by the Pennsylvania State Department of Health[6] describes effective methods of treatment developed by joint studies by this industry and the Pennsylvania Department of Health.

At the oil refineries strengthening of the loading and unloading pipe lines from plants to barges and tankers and the installation of baffled oil skimming traps to handle unavoidable leakages have removed unnecessary oil discharges from the water.

One of the most difficult wastes encountered in this area was the discharge from the alcohol distillery known as "molasses slop." This untreated waste has a 5-day, 20° C. biochemical oxygen demand eighty times that of domestic sewage. This material contains valuable substances such as unfermentable sugars, glycerine, potash and ammonia. For a short time after the war a process which recovered potash and ammonia entirely eliminated the discharge from the bay, with profit from the sale of the by-products. Today the recovery process, to which improvements are being constantly applied, is rather costly and should, if possible, be replaced by another means of disposal.

The "molasses slop" containing about 90 per cent of water is settled in tanks, whence it is pumped to quadruple-effect evaporators where the moisture content is reduced to about 50 per cent. The effluent from the evaporators passes through incinerators where a potash clinker is produced. A Cottrell precipitator originally recovered the "fines" from the incinerator. This equipment has recently been replaced by a bag type filter which completely eliminates the original aerial nuisance and increases the recovery of potash. Leaving the precipitator the gases pass to an ammonia recovery unit where their induction into sulphuric acid produces commercial ammonium sulphate, a fertilizer material. The latter unit is now in need of reconstruction but the market price of ammonium sulphate has not warranted the expenditure. The magnitude of this particular problem may be indicated by the fact that the installation of the complete treatment was made at a cost in excess of a million dollars. During normal production the total "molasses slop" discharge is 400,000 gallons per day.

To eliminate the acid and ferrous sulphate bearing wastes from the rolling mills mechanical scale removers and refrigeration were suggested. It was not considered economically practical by the mills to comply with these suggestions and some experimental work was conducted in their laboratories which has not as yet been completed. Dilution water in the vicinity of these mills has been sufficient to allow discharge of the wastes, only, however, after the quantities of acid used for pickling were considerably reduced by the adoption of scientific methods of testing their pickling tank effluents in place of the taste method. Saving in acid consumption fully justified the change.

The stream problems of the Curtis Bay and Baltimore Harbor area were solved by 1923.

In the Upper Potomac River section, within a stretch of 25 miles on the river, the wastes consisted of those from a large pulp and paper mill, a hydroelectric plant, a rubber tire manufacturing plant, a wood creosoting plant, a silk textile mill and coal mine drainage. Untreated domestic sewage from a municipality with a population of 38,000 enters the river just below the concentrated industrial load.

Rapid progress is being made in the difficult area on the Upper Potomac River. At this point the industries are so interrelated with respect to their uses of the river for plant processes, boiler, condenser and waste carriage that it became necessary early in 1929 to organize the group of industries and sponsor an analytical study of the problems. The Bureau of Sanitary Engineering, acting in a supervisory capacity, formally organized the group as "The Upper Potomac River Board." The program adopted comprises complete chemical analyses of the river water weekly and the establishment of stream gaging stations at strategic points on the river. The group, including the municipality contributing raw sewage, finances the work and the U. S. Geological Survey contributes part of the expense of establishing and controlling the stream gaging stations. The State Department of Health, represented by the Chief Engineer of the Bureau of Sanitary Enginering, assumes supervision of the entire program, reviews regularly the data and outlines current procedures in the studies. Two years after organization the first report of the Board summarizes the activities and results accomplished. A review of this report is available.[3]

The scattered problems in other sections of the State have been due chiefly to numerous small canneries, milk handling plants and smaller paper mills. Thus far, with a few exceptions, canneries have not progressed beyond screening. Improvements in the operation of milk condensing and powdering equipment and chlorination of waste waters from this industry have produced improvements. Ten of the twelve paper mills of the State are relatively small and located on streams in isolated

sections. Investigations indicate that they offer little if any trouble. The two larger mills have installed adequate save-all systems with phenomenal recovery of waste.

Perhaps the most difficult of the wastes outside of the two industrial areas, referred to above, with which we have had to deal has been those from the disposal of the garbage of Baltimore by the reduction process. For the past six years a number of added improvements to the grease and tankage recovery processes had been developed, although the city has now abandoned the reduction process of disposal and reverted to combined high temperature destruction or incineration with trash.

The reduction plant originally removed grease by the crude and inefficient method of hand skimming. The pressed solids from the digesters were dried by direct heat without provisions for removing consequent odors. The 5-day, 20° C. biochemical oxygen demand of the discharge from this process averaged two hundred times that of domestic sewage and the relatively small tidal receiving waters were near permanent shore communities and summer colonies. The essential equipment to improve the aerial and water nuisances which existed consisted of a revolving fine mesh screen, settling tanks providing 24 hours detention, Tolhurst and DeLaval separators and a scrubber equipment provided with chlorine treatment for the tankage drier stack gases. The final discharge from the digestion and grease separating processes was treated with calcium hypochlorite. Conditions were somewhat improved but further treatment would have been required had the plant continued to operate.

An interesting problem of special local interest was the investigation of wastes from a chenopodium oil plant. Practically all the chenopodium oil in use in this country several years ago was produced in Carroll County, Maryland. This oil is employed for the treatment of hookworm. Extensive experiments were conducted with native fish to determine the tolerance of fish to pollution by escaping chenopodium oil which was the only source of waste. It was concluded that death was due directly to the toxicity of the oil and that native fish could withstand longer than three hours contact with 50 parts per million content of oil before death ensued. Filming, oxygen depletion and increase in acidity were not attributable causes.

Statistical data compiled from a recent complete inventory of the industrial waste discharges into Maryland streams is to be found in a report of the Maryland General Assembly in February, 1933, by the Water Resources Commission of Maryland. The Commission was appointed in 1931 Session of the Assembly to prepare recommendations as to policy, legislation and methods of financing for the preservation of water supply resources of the state.

Numerous problems in aerial pollution resulting from industrial waste

discharges into the atmosphere have demanded attention in Maryland. From the standpoint of health probably the most important study was that of hydrogen sulphide in the vicinity of a purification plant for blast furnace and coke oven gas. The toxic minimum of this gas is given at about 0.005 per cent by the U. S. Public Health Service.[4] The hydrogen sulphide was being incompletely removed by passing the gas from the blast furnaces and coke ovens through iron oxide boxes and discharging it from a stack 90 feet in height. In 1923 the Koppers Company introduced a liquid gas purification method. By this method the unpurified gas is passed through a tower while soda ash solution is sprayed downward through it. A large portion of the hydrogen sulphide is absorbed. The spent soda ash solution is blown with air and the occluded hydrogen sulphide is released and passed into the air from the top of the stack which was subsequently raised to a height of 200 feet. The improvement was negligible. Hydrogen sulphide concentrations as high as 0.029 per cent were found 700 feet from the plant which is located in a semi-urban community of considerable size. As a result of further activities of our Department temporary measures were taken to alleviate the nuisance by the installation of burners in the lower portion of the purification tower in order to raise the temperature of the gas, thereby sending it to higher levels for greater dispersion and dilution.

Laboratory experiments by the Koppers Company culminated in the construction of a supplemental unit designed for complete elimination of the hydrogen sulphide discharge. The general principles of the supplemental unit involved treatment of the exhaust gas from the stack by means of specially prepared iron turnings, together with a patented catalyst. Poisoning of the catalyst by cyanogen in the gas presented further difficulty. This was finally overcome and no hydrogen sulphide was then discharged when the plant operated at full capacity, removing 6 tons of hydrogen sulphide and 2 tons of hydrogen cyanide per day. The resulting sulphur sludge is handled by spreading in the open in layers about 8 inches thick. Filter pressing of the sludge was found to be unsatisfactory. Additional information concerning this and other special problems of atmospheric pollution by industrial wastes in Maryland was presented by Abel Wolman[5] at the 1929 Convention of the American Public Health Association.

It is obvious that the industrial wastes problem is the sanitary engineers' "baby." Chemists and chemical engineers are essential coöperative agencies. It has been frequently observed in Maryland that chemists working in the field of water purification, sewage treatment and stream pollution approach the problem of industrial wastes from a different angle than the average manufacturing chemist. Not infrequently the sanitary chemist quickly discovers that minor changes in manufacturing operations

will materially assist in solving the waste problem and perhaps salvage valuable products. The possibilities of the development of by-products from manufacturing wastes should be of continuous interest to manufacturing chemists. No program of research in the field of industry is complete without a section devoted to the study of waste products.

Acknowledgment

I wish to express appreciation of the assistance of Mr. Abel Wolman, Chief Engineer of this Bureau, for his critical review of this paper, to the Bureau of Chemistry of this Department and to former and present members of the staff of the Bureau of Sanitary Engineering of the Maryland Department of Health for coöperation in supplying information.

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Editorial

B. O. D. and Chlorination

Those magic letters "B. O. D." should be adopted as the slogan or password of the fraternity of sewage works chemists. The biochemical oxygen demand represents the most important and most interesting part of the routine records of sewage plant performance, and it is accepted as the best measure of plant efficiency, stream pollution or waste disposal. The apparently simple technique of the determination, as ordinarily made, leads to a feeling of dependability that is by no means justifiable when complicating factors arise due to the use of chemicals in sewage treatment. When the test is used by some one with experience on normal sewage or effluents, the results are quite reliable. When, by certain types of treatment the normal flora and fauna in the sample are disturbed, changed or eliminated, the use of the B. O. D. method can often lead to illogical results that puzzle even those who have studied the method for years.

For instance, consider the effect of chlorine on clarified sewage. Chlorination is a relatively simple procedure, but it produces a profound change in the living and dead organic matter in the sewage to such an extent as to require careful work, experience and common sense in the interpretation of the results of the B. O. D. determination when applied to such effluents. It is hardly an exaggeration to say that we still know very little about the actual effect of chlorine on the oxygen demand of sewage or sewage effluents, in spite of the many publications on this subject.

A very interesting investigation of the effect of a chlorinated Imhoff effluent on a receiving stream is reported in this issue (p. 429) by Baity, Merryfield and Uzzle. This was referred to by Enslow as "the most conclusive of all hitherto reported investigations." (THIS JOURNAL, **4**, 255 (March, 1932).) The reader is referred to the article for details of the work.

In connection with the discussion of the chlorinated Imhoff effluent, the statement is made (p. 442), "An opportunity was afforded to check former findings on the reduction of B. O. D. of settled sewage by chlorination, as represented by the test applied to the effluent immediately before and immediately after the treatment. The results indicate an average reduction from 86.7 to 52.0 p. p. m., or 40.0 per cent, which corroborates nicely the published results of ourselves and other investigators who have studied this phenomenon." The results here referred to were for seven days, from August 19 to 25, 1930, inclusive. The chlorine applied aver-

aged 12.2 p. p. m. and the residual was 1.4 p. p. m. However, later, from Sept. 1 to 3, 1930, inclusive, the chlorine applied averaged 18.4 p. p. m., with a residual of 4.0 p. p. m.; the B. O. D. of the unchlorinated samples averaged 45 p. p. m. and of the chlorinated samples 0.0 p. p. m., or *an apparent reduction of 100 per cent.* Likewise the stream had an apparent B. O. D. of 0.0 for some distance below the outfall. A note states that these results were disregarded.

Although disregarded in the averages, the zero B. O. D. results are significant as indicating what may happen with a large residual chlorine content. It hardly seems possible to conceive of a complete and permanent reduction of the B. O. D., from 45 to 0.0 p. p. m., merely by the addition of 18.4 p. p. m. chlorine. The explanation of these results is probably that the samples were thoroughly sterilized, and the residual chlorine was not successfully neutralized nor the sample seeded with the necessary organisms before the B. O. D. was determined, consequently there was no loss of oxygen and apparently a zero B. O. D.

In the other results, accepted as reliable, the chlorine applied averaged 12.2 p. p. m., the residual was 1.4 p. p. m. The B. O. D. was reduced from 86.7 to 52.0 p. p. m., equal to 40.0 per cent. These results were not questioned. If, perchance, 15.0 p. p. m. had been applied and a residual of 2.0 or 3.0 parts obtained, might not the *apparent* B. O. D. reduction have been 60 or 70 per cent? In other words, where do we leave the range of impossible reductions and enter the range of acceptable reductions?

In the earlier work reported by Baity and Bell (THIS JOURNAL, **1,** 279 (April, 1929)) the following data were presented as the results obtained by chlorination of the Chapel Hill Imhoff effluent:

Chlorine, P. p. m.		B. O. D., P. p. m.		Reduction	
Applied	Residual	Unchlorinated	Chlorinated	P. p. m.	%
5– 7.5	0.0	77.0	71.1	5.9	7.4
8– 9	Trace	94.3	79.6	14.7	15.5
10–15	0.2–0.5	85.2	48.9	36.3	42.7

This is a surprising result; addition of 8 to 9 p. p. m. chlorine apparently produced a B. O. D. reduction of only 14.7 p. p. m., or 15.5 per cent, while addition of 10 to 15 p. p. m. chlorine apparently produced a far greater reduction of 36.3 p. p. m., or 42.7 per cent.

Another example comes to mind. In the results reported by Carpenter (THIS JOURNAL, **4,** 258 (March, 1932)) the summary shows the following data:

Screened Sewage Chlorine, P. p. m.		B. O. D., P. p. m.		%
Applied	Residual	Unchlorinated	Chlorinated	Reduction
5.8	0.5	77	32	58.4
3.2	0.0	83	70	15.7

It seems quite unlikely that application of 5.8 p. p. m. chlorine could

cause a true and permanent reduction of 45 p. p. m., or 58.4 per cent, while slightly less (3.2 p. p. m.) accomplished a reduction of only 13 p. p. m., or 15.7 per cent.

The probable explanation is that when chlorine is applied heavily, to produce a substantial residual amount, the natural flora and fauna are practically eliminated, whereas if chlorine is not added to leave a residual amount, the organisms are not eliminated and, when allowed to grow, again account for a substantial oxygen consumption. The lag period of bacterial growth is apparently greatly extended when a large residual is obtained.

Further examples could probably be found, where the application of a large amount of chlorine, and the production of a large residual, has resulted in an *apparent* reduction of B. O. D. far beyond the limits of probability or credulity. On the other hand, at Dearborn, for example, application of 35 or 40 pounds of chlorine per million gallons, with no residual, apparently accomplished nothing in the further removal of B. O. D.

Enslow, Tiedemann and others long ago showed that there was a remarkable improvement in bactericidal efficiency when chlorine was applied to give a substantial residual, as compared with slightly lower addition of chlorine, with no residual.

This situation leads to the conclusion that considerably more careful research must be carried on to determine the true effect of chlorination on the B. O. D. The work of Baity, Merryfield and Uzzle shows conclusively that chlorination produced a remarkable change in the physical appearance of the stream for a short distance below the outfall, that the dissolved oxygen increased substantially for a distance of 1 mile below the outfall, but hardly appreciably at a distance of 4 miles down-stream, and likewise the B. O. D. was apparently reduced markedly at a station 2500 feet below the outfall, but very little (from 3.5 to 2.9 p. p. m.) at a distance of 4 miles down-stream. Unfortunately the time of flow of the stream from the outfall to the various stations was not reported, due to difficulties in determining the velocity, although the authors estimate the last station to be several days downstream "in times of severe drought." The significant reduction in B. O. D. and increase in dissolved oxygen occurred at Station 6, only 2500 ft. below the outfall, and probably less than 2 or 3 hours in time of flow. Unfortunately there are no B. O. D. results for Stations 7 and 8, which are also only a short distance below the outfall (3000 ft. and one mile).

The sloughing off of slimy growths below the outfall, during chlorination, was similar to results reported below Leipzig some years ago. While this might be desirable locally, the question arises as to whether it may not cause a nuisance farther down-stream.

We hope this discussion will not give the impression of a carping criti-

cism of what is really an excellent piece of work. The data accumulated by Prof. Baity are, as stated by Enslow, the most conclusive of all hitherto reported investigations, and they show many advantages accomplished by the use of chlorine with clarified effluents in the immediate effect on the receiving stream, but more work remains to be done along similar lines before we can feel confident about the effect of chlorine as measured by the conventional B. O. D. method and as applied to the practical disposition of the effluent when times of flow extend over many days. The problem should some day be tackled by the U. S. Public Health Service, under the direction of Hoskins, Streeter, Theriault, Purdy and Butterfield. Baity's work would be a fine foundation for such an investigation on a larger scale.

Employment Service

(1) DESIGNER thoroughly experienced in design and construction of sewage treatment plants. Just completed one year with general contractor on sewage treatment plant job. Previous four years drafting and design work in sanitary engineering. Total experience twelve years since graduation. Age 37. Married. Assoc. Mem. A.S.C.E.

(2) M.S. in SANITARY ENGINEERING, 1932, Michigan State College. Seven years with the Michigan State Highway Commission. Municipal engineering, including construction of water mains and sewers. Assistant instructor in sewage operators school. Publications on trickling filters and stream pollution. Age 31. Married.

(3) SANITARY ENGINEER, graduate M. I. T., four years experience in design of sewers and sewage treatment works, five years experience in investigating industrial wastes, designing and operating sewage testing stations, and investigating and developing methods and apparatus for sewage treatment. Three years as asst. supt. of large activated-sludge plant. Desires position to design or operate treatment works or to aid in the development of new processes and apparatus for sewage treatment. Age 36. Married.

(4) CHEMIST AND BACTERIOLOGIST, university graduate, six years superintendent of water filtration plant, past five years in sewage works laboratory, in charge of plant control. Recent experience in sludge filtration and disposal. Age 37. Married.

(5) SANITARY ENGINEER, M.S. from Michigan State College. Experience in highway and railway work. University work in soil bacteriology. Age 25. Single.

(6) SANITARY CHEMIST AND BACTERIOLOGIST, B.S. in Chemical Engineering, M.S., four years experience in sewage and water treatment, principally research and development at state experiment station, recently with prominent consulting sanitary engineer, publications. Age 27. Single.

(7) SANITARY ENGINEER. More than ten years experience in designing, building and servicing mechanical equipment used in sewage treatment works, such as screens, clarifiers, digesters, aerators and pumps. Design and construction of paper mill and beet sugar factory. Age 37. Married.

(8) SUPERINTENDENT of sewage works. Ten years experience as Superintendent of small Iowa sewage treatment plant. Has also had charge of municipal garbage incineration works. References. Age 39. Married.

Proceedings of Local Associations

New York State Sewage Works Association
Notice of Spring Meeting

Friday, June 9

The Spring Meeting of the New York Sewage Works Association will be held at the Hotel Seneca in Rochester, June 9 and 10, 1933. A full and varied program will include the following papers:

1. "Some Things That Have Been Learned About Aeration in Sewage Treatment," by Frank C. Roe.
2. "Vacuum Filtration in Sewage Treatment," by W. G. Taylor.
3. "Sewage Treatment and Operating Problems at Jamestown, N. Y.", by L. A. Bergman.
4. "Some Headaches of an Ex-Operator of Sewage Treatment Works," by John Lewis.

Mr. Bergman's paper will be followed by a symposium on the operation of small sewerage systems and treatment plants under the leadership of W. A. Ryan of Rochester.

Saturday, June 10

A Sunrise Breakfast will be followed by a Question Box and Round Table discussion conducted by Morris Cohn of Schenectady. The remainder of the morning session will be devoted to the presentation of two papers, one by Glenn D. Holmes and the other by R. G. McDonald, describing the special features and operating experiences at the Newark plant and the East Rochester plant, which will be visited in the afternoon.

A. S. BEDELL, *Sec.-Treas.*

Ninth Annual Meeting of the Michigan Sewage Works Association

East Lansing, March 30–31, 1933

The Ninth Annual Meeting of the Michigan Sewage Works Association was held at Michigan State College, East Lansing, on March 30–31, 1933. Prior to the meeting of the Association a two day short course in methods of analysis was given by the members of the College staff. The work was

divided into two groups, one for those desiring instruction in bacteriology and the other for those asking instruction in methods of chemical analysis. The latter group was again subdivided into the solids series of analysis and the oxygen series. Appropriate lectures accompanied the laboratory work. Some twenty-five attended this short course, an increase of two over the preceding year. Total attendance at the conference was 75.

Mr. E. C. Miller opened the conference with a paper on the Chemical-Mechanical Treatment of Sewage at Dearborn. Mr. Miller described the various processes employed at Dearborn and the degree of purification being obtained at this plant. Because of the peculiar conditions existing at Dearborn no operating cost data was presented. Following the presentation, a very lively discussion ensued which continued until adjournment for lunch.

Pres. R. S. Shaw of Michigan State College opened the afternoon session with a short talk to the Association, extending the hospitality of the College to the organization.

A talk on Prevention of Accidents at Sewage Treatment Plants was given by Mr. R. E. Kelley of Sturgis. Lack of time prevented a complete discussion of the topic, but several very important points were developed by Mr. Kelley. It seemed to be the consensus of opinion that further papers along this line should be presented.

Dr. Carl Hubbs of the Institute of Fisheries, University of Michigan, presented a highly interesting talk on the Relationship of Sewage Pollution to Fish Life. He emphasized the fact that the present information on the subject is exceedingly limited and states definitely that no fixed standard of pollution has yet been set up which can be satisfactorily accepted for all conditions. Food, oxygen conditions, temperature, change in conditions were all emphasized as being highly important factors in maintaining satisfactory fish life.

The experiences in sewage chlorination at Flint, Michigan, over the past three years were briefly summed up in a paper by Mr. P. R. Welch of Flint. He spoke of their experiences in chlorination for several purposes, including odor control, both at the plant and in the long conduit delivering the sewage to the plant; on relief of pooling on trickling filters; on attempted chlorination for relief of loading on a stream prior to completion of the treatment works, and upon control of plankton and algae in the stream following the installation of the filters. This paper in conjunction with other papers presented before gives an accurate picture of the accomplishments and limitations of chlorination of sewage at Flint.

A dinner at the Michigan State College Union Building was well attended. Mr. R. A. Smith, Michigan State Geologist, was the speaker of the evening, describing generally the geological formations of the State, and the recent developments in the oil fields.

Mr. N. G. Damoose of Grand Rapids presented an interesting talk on pH determinations. Mr. Damoose has conducted several series of experiments with five different kinds of apparatus for measuring pH. Determinations were made by all the different types of apparatus on samples of distilled water, tap water, raw sludge, diluted raw sludge, clear liquor from sludge and several others and showed by means of graphs the results obtained from each piece of apparatus.

Descriptions of the activated sludge plants at Muskegon Heights, Escanaba and Woodstock, Illinois, were given by Mr. L. D. Suhr of Chicago, designing engineer for these plants. All three of these plants use mechanical aeration, and the first two a combination of paddle wheels and air blowing. A gas engine using digester gas for fuel furnishes part of the power at Escanaba.

M. P. Adams, Secretary of the Michigan Stream Control Commission, gave a short talk on financing the construction and operation of sewage treatment works. A recent opinion of the Attorney General relative to charges for sewer service by municipalities was presented. The possibility of using this type of work for relief of unemployment was also developed.

A highly interesting talk on Utilization of By-products of Sewage Disposal was given by James R. Rumsey of Grand Rapids. This paper was wholly free from technical discussion but was devoted to a consideration of other phases of plant operation such as plant beautification, securing the support and good will of the community, the use of available ground for garden purposes, utilization of gas and producing and marketing fertilizer.

A "Question Box" conducted by C. T. Mudgett of Pontiac proved very interesting and excited a good deal of discussion. This feature of a program appears to be very popular.

At the annual business meeting the following officers were elected for the year 1933: *President*, C. T. Mudgett, Pontiac; *Vice-Pres.*, P. R. Welch, Flint; *Sec.-Treas.*, W. F. Shephard, Lansing; *Director*, M. P. Adams, Lansing; *Continuing Director from 1932*, E. F. Eldridge, East Lansing.

W. F. SHEPHARD, *Sec.-Treasurer*

The Seventh Annual Conference. The Maryland-Delaware Water and Sewerage Association

Baltimore, May 4 and 5, 1933

The Maryland-Delaware Water and Sewerage Association held its Seventh Annual Conference at the Southern Hotel in Baltimore on May 4

and 5, 1933. A total of 176 attended, the largest registration the Association has had since its organization.

The opening address given by Mr. Bernard L. Crozier, Chief Engineer of Baltimore, was followed by a paper entitled "Stream Control in Maryland—Activities, Report and Accomplishments of the Water Resources Commission of Maryland," by Mr. F. H. Dryden, City Engineer of Salisbury. Mr. Dryden emphasized the need of an intelligent plan of water measurement in New Jersey. A permanent policy, a program and an administrative agency he cited as the essential prerequisites to a method for gaging water resources.

Mr. H. Roland Devilbiss, Department Engineer, Washington Suburban Sanitary District, Hyattsville, Maryland, presented a paper "Cast Iron Pipe and Fittings for Sewer House Connections." In the construction of 160 miles of sewers and 8700 house connections in the Washington Suburban Sanitary District it was concluded "that a sewer house connection constructed of cast-iron pipe and fittings from the main sewer to the property line or through to the house with joints of leadite, mineraled, sulphur compound and lead, provides a cheaper service in first cost, at least as durable, if not more so, than can be secured with any of the other types of pipe commonly used for this purpose, and most certainly a service lower in maintenance cost."

Solutions to the problem of overcharging sanitary sewers in violations of regulations in force at the time areaway drains were permitted were discussed in "Cellar and Open Area Connections to Sanitary Sewers," by Ellwood Johnson, Associate Maintenance Engineer, Sewer Division, Washington, D. C. It was suggested that periodical reinspection of all premises abutted by sanitary sewers, with attendant strict enforcement of the revocable permits for installation of area and depressed driveway drains would solve the problem.

"Sewage Treatment in Germany," was an interesting paper given in motion pictures by Stanton L. Dorsey, Construction Division, Veterans Administration, Washington, D. C.

Mr. Harry E. Jordan, Sanitary Engineer of the Indianapolis Water Company delivered the address at the Annual Dinner. He spoke of the importance of the part played by the operator and his responsibility in continuing the life and industry of his community.

A description of the sewage treatment plant at Wilmington, Delaware, was given by Harry L. Maier, Chief Engineer, Street and Sewer Department, Wilmington. The plant, which was completed in March, 1932, and cost $81,450, consists of a grit chamber, 3 primary tanks, 2 dosing tanks, 2 Adams type sprinkling filters, 1 final tank, 2 sludge tanks and a sludge bed.

Inspection trips were provided to Vernon, Guilford and Towson water

pumping stations; Eastern Avenue storm water pumping station, Philadelphia Road Incinerator and Back River Sewage Treatment Plant; and New Baltimore Incinerator and Crownsville State Hospital Water and Sewage Treatment Plants.

At the business meeting it was decided to hold the Eighth Annual Conference in Washington, D. C., in 1934, and the following officers were elected: B. E. Beavin, Annapolis, Maryland, *President;* C. J. Lauter, Washington, *First Vice-President;* L. D. Shank, Dover, Delaware, *Second Vice-President;* A. W. Blohm, Baltimore, *Secretary;* E. S. Hopkins, Baltimore, *Treasurer;* L. R. Voris, Hagerstown, Maryland, *Executive Committee*

A. W. BLOHM, *Secretary*

Reviews and Abstracts

H. W. STREETER

Report of the British Water Pollution Research Board for the Year Ended 30th June, 1932, with Report of the Director of Water Pollution Research

The fifth annual report of the Water Pollution Research Board is a notable contribution to the literature of stream sanitation, worthy alike of its immediate predecessors and of its more remote forbears, the classic reports of the Royal Commission on Sewage Disposal. The detailed report of the Director, Dr. H. T. Calvert, follows a general statement by the Chairman and deals in turn with the various research projects under way, including the disposal of beet sugar factory effluents, the survey of the River Tees, the activated-sludge process of sewage treatment, colloids in sewage, the base-exchange method of water softening and plumbo-solvency of waters.

Disposal of Beet Sugar Effluents.—Large-scale experiments on the purification of beet sugar factories' effluent have been carried out at Colwick, and laboratory experiments at Rothamsted. Preliminary studies also have been made of the purification of milk wastes and of conditions affecting results obtained from the 5-day B. O. D. test.

In the experiments at Colwick, the value of inoculating a percolating filter with certain organisms believed to be especially efficient in oxidizing sugar has been investigated. Using a control filter not inoculated with the organisms, parallel observations were continued throughout the season, from October 21, 1931, to January 4, 1932. Although the inoculated filter gave a percentage purification only slightly better than that which was not inoculated, it is stated that further investigation should lead to the selection of strains more efficient than those used in the experiment.

The laboratory experiments at Rothamsted during 1930–31 had dealt with the biological filtration of sucrose, lactic acid and acetic acid, with and without nitrogen, using clinker filters built in six tiers. A similar filter has been used during the past year and further experiments have been made on the biological oxidation of 0.1 per cent sucrose solution in the presence of nitrogen added separately as ammonium salt, sodium nitrite and sodium nitrate. Further experiments also were made with

glass filters filled with small pieces of glass tubing, facilitating analysis of the biological films built up in the filters.

The results of the experiments have shown that for efficient oxidation of sucrose by biological filtration, suitable compounds of nitrogen, phosphorus and potassium should be present. Ammonium salts and sodium nitrite and nitrate were equally efficient as sources of nitrogen and best results were obtained when the carbon:nitrogen ratio was about 15:1. The optimum amounts of phosphate and potassium are as yet undetermined.

Preliminary investigations of the B. O. D. test as applied to beet sugar effluents have shown that the absorption of oxygen is affected by dissolved salts and nitrogenous compounds in the dilution water used and by the initial bacterial content. The amount of oxygen absorbed in 5 days is stated rarely to exceed $^2/_3$ of that required for complete oxidation of the sucrose. It is suggested as possible that the unoxidized portion is transformed into bacterial tissue.

Preliminary experiments have been made on the treatment of waste liquids containing milk. Although excellent results were obtained on the laboratory filter, ponding was experienced and observations are being continued with a modification of the wood-lath filter used by Levine at Iowa State College.

Survey of the River Tees.—Considerable progress has been made during the past year with the chemical and biological observations, which are nearing completion. Further information is being obtained on the flora and fauna and, chiefly in the non-tidal reaches, on the decomposition of sewage.

Tidal Estuary.—The large mortality of salmon and sea-trout smolts during their annual migration through the Estuary has been found to be due largely to the presence of cyanides and tar acids in the river, rather than to a deficiency of dissolved oxygen. The most important source of these toxic substances has been coke oven and similar effluents.

The production of coke oven effluents containing cyanides can probably be avoided by altering the methods of gas washing and cooling. Experiments in the removal of cyanides from the effluents have indicated that treatment with spent iron pickling liquor containing ferrous chloride, or spraying the effluent in a fine mist at 60° C., will effect a substantial reduction in the cyanide content. Addition of lime with the pickling liquor accelerates the process of removal.

Observations on the toxicity of phenols and paracresols have shown that these two substances produce greatly augmented toxic effects when present together. Neither substance increases the toxicity of cyanides. The reason appears to be in the similar physiological effects produced by para-cresol and phenol and in their dissimilarity to cyanides in this respect.

A study of the factors affecting the rate of disappearance of toxic chemicals in the Estuary water has shown that under aerobic conditions, sewage accelerates the decomposition of phenols and para-cresols very strikingly, but does not appear to exert a similar effect on cyanides, which even in small concentrations inhibit the decomposition of sewage.

An assessment of the relative deoxygenating effect of the various effluents discharged into the Estuary has been continued, all of the main effluents having been examined. The B. O. D. of sterile industrial effluents depends so largely on the bacterial content of the diluting water that a standard procedure of using Estuary water for this purpose has been adopted.

Further surveys of the flora and fauna of the Estuary have revealed about the same species and distribution as previously. These are described in detail.

Non-Tidal Reach.—Observations of self-purification in the non-tidal section of the river have shown that the rate of purification is influenced mainly by temperature, being more rapid in summer than in winter. Experiments have been made on the changes taking place in sewage diluted in tanks equipped with stirrers and temperature control. These changes were found to be very similar to those occurring in the river. Intermittent exposure of the water to light increased the rate of bacterial production and the rate of chemical breakdown. Continuous exposure lowered both rates.

In connection with a study of the breakdown of sewage in the river, experiments have been conducted on the toxicity of sewage to trout. Fresh sewage, when diluted 10:1, had no injurious effect; undiluted sewage had a slightly toxic effect. If the sewage is allowed to decompose anaerobically and then diluted, the mixture is toxic to trout. This toxicity was found to be due to the development of sulphide. A concentration of 3 p. p. m. of sulphur is lethal to trout in five minutes. From these studies it was concluded that fresh sewage under aerobic conditions in a river has no injurious effect on fish until marked depletion of dissolved oxygen has occurred and the food supply may have been affected.

Activated Sludge Process of Sewage Treatment.—The purification of sewage by means of activated sludge is being investigated to obtain information on the biological changes occurring at different stages of the process. In this connection, a study has been made, during the past year, of the factors involved in the absorption of oxygen and of the possibility of devising an improved method of following changes in oxygen demand in the experimental tank.

An attempt was made first to determine the relative importance, in regard to the 5-day test, of various constituents of crude sewage: viable bacteria, bacterial or other enzymes and oxidizable substrate. To this

end experiments were made with sewage sterilized by heat, by filtration and by different bactericidal chemical agents.

It was found that after sewage had been effectively sterilized and bacterial growth entirely suppressed, no oxygen absorption occurred, though a small seeding with fresh sewage into sewage previously sterilized by heat or filtration would restore the 5-day B. O. D. to its original value. Experiments with sewage heated at various temperatures indicated that different bacterial species might vary in their oxygen demand when growing in the presence of crude sewage substrates and that heating at 55° C. might bring about a limitation of the bacterial flora to species whose oxygen demand was low. The fact that autoclaved sewage, when seeded, gives a high B. O. D. figure, shows that heating does not diminish the oxidizability of the substrate.

From these results it may be concluded that two factors at least are concerned in the 5-day B. O. D. test: (*a*) oxidizable substrates, and (*b*) oxidizing agents in the form of growing bacterial cells, or enzymes, probably of bacterial origin.

Experiments have been carried out with the methylene blue test, using Thunberg tubes, which can be readily evacuated. From the results, it would appear that if the time of reduction of methylene blue by the activated sludge used in the control experiment is of the order of one hour and the time of reduction with the sewage-sludge mixture is not less than 24 hours, the sewage may be regarded as fairly well purified. It seems possible that the methylene blue test, as modified in these experiments, may be of service in research work, at least. It appears to be a distinct advance on the methylene blue test in current use.

Other Studies in Progress.—An investigation of the nature and amount of colloids in sewage has dealt thus far with sewage from the disposal works at Croyden, though it is planned to extend the scope of these observations. A classification of the dispersed materials of sewage is being undertaken; by physical methods involving the use of filters and ultrafilters, gravity sedimentation and centrifuging and by chemical means, which are being studied. The results of these determinations, which are presented in tabular form, indicate that the dispersed matter may be divided into three classes according to size of particles by centrifuging the sewage at 2500 r. p. m. The coarser material, separated after a few minutes, contains one-half to three-quarters of the organic carbon. Of this coarser matter, about two-thirds can be removed in a few hours by simple gravity sedimentation. The very fine particles, not separated at 2500 r. p. m., contain nitrogen and are possibly of protein character.

A committee of the Institution of Gas Engineers has been studying jointly the two related problems of gas works effluent disposal and of ammonia recovery. A study has been made of a closed liquor circulating

system combined with a cyclone tar extractor acting on hot crude coal gas, and experiments have been conducted on the extraction of phenols and higher tar acids by means of various solvents. These experiments have indicated that extraction can be accomplished by benzol, tricresylphosphate and certain tar oils, but that paraffin, carbon tetrachloride and gas oil are unsatisfactory.

Other investigations being conducted by the Board are concerned with the base-exchange, or zeolite, process of water softening and with the treatment of corrosive or plumbo-solvent waters. As these topics are of lesser interest to sewage workers, they are omitted from this review. A copy of the full report may be obtained from the Department of Scientific and Industrial Research, 16 Old Queen Street, Westminster, S. W. 1, London, England, at a price of one shilling, net. H. W. STREETER

Annual Report of the Ruhrverband, 1932

BY DR.-ING. K. IMHOFF

The very interesting annual report of the Ruhrverband for 1932 is well illustrated with diagrams and pictures. It summarizes the work done during the year and includes a detailed discussion of the financial condition.

Up until the end of May there was sufficient water in the Ruhr River, but during the next four months the flow was only about one-half of the average. The discharge of industrial wastes decreased during the year still further although some idle plants have recently reopened. As a result of an adequate flow of water and a decrease in industrial wastes, conditions at the water works, on the whole, have been good. In a complete investigation of the Ruhr, at low water, only four places of strong local pollution were found. Conditions on the Lenne River have improved, resulting in a decrease in the pollution of the Hengsteysee, where biological conditions have improved and the stock of fish has increased greatly. In Harkortsee fish diseases appeared but they were not traced back to sewage pollution. During the warm season of the year the Ruhr is used for bathing along its entire length, even more than formerly. An investigation showed that the Ruhr territory is not contributing to the pollution of the Rhine. Both the Hengsteysee and Harkortsee have been very successful in purifying the water. The construction work on Baldeneysee, which had been discontinued toward the end of 1931, was resumed in February, 1932, utilizing unemployed labor. It was intended to fill the lake in January and to put the power plant in operation about April 1, 1933. If a few improvements are made the Ruhr will be navigable for ships up to 320 tons from the Rhine up into the Baldeneysee. Except

for the work on the Baldeneysee, little construction was done. Economies were made in the operation of treatment plants and pumping stations, made possible because of the decrease in industrial wastes and the increase in the dilution. Investigations have shown that, during three years operation, the Oelbach pond has prevented about 31,000 cubic yards of sludge from going into the Ruhr.

A 120-hp. gas motor was installed at the Essen-Rellinghausen treatment plant which, by utilizing the gas from the sludge digestion tanks, furnishes all the power required for the plant operation and made possible the reopening of Plants I and II, which had been taken out of operation for economic reasons. The cost of construction of the gas power plant was defrayed by savings in operation. At the treatment plant in the city of Hattingen the digestion space of the Imhoff tanks was supplemented by the addition of a horizontal, cylindrical secondary digestion tank about 65 feet long and 18 feet in diameter. The digestion tank, which consists of a corrugated sheet iron boiler, encased in reinforced concrete, is heated with the condenser water from the gas motor, led in through a horizontal movable pipe. This heating pipe can also be used as stirring apparatus to break down the scum. Since the boiler, lying above ground, is higher than the water level of the Imhoff tanks, an air lift is used to draw the sludge from the Imhoff tanks. Through the use of the secondary digestion tank, the gas yield of the plant has been doubled and is now sufficient for complete operation of the biological plant. A fish pond which has an area of 27,000 square feet and a depth of about 4.25 feet has been built behind the Imhoff tanks at the Hattingen-Ost treatment plant, providing biological secondary treatment of the sewage in the simplest way. Activated-sludge tanks were added at Velbert, since partial purification of the sewage in Imhoff tanks and submerged contact aerators were not sufficient. A second sprinkling filter and a secondary settling tank were added to the Neviges treatment plant. About 0.6 mile of sewer was built in Hügel and Werden on Baldeneysee, 0.75 mile at Oelbach and 3.7 miles in Altenhundem/Meggen. The Ruhrverband now operates 75 treatment plants, about 137 miles of sewers and 15 pumping stations. G. P. EDWARDS

Mechanics of the Activated-Sludge Process

BY C. LUMB

The author states the fundamental points of the activated-sludge process of sewage treatment, discusses briefly the older theories in explanation of the phenomena of this principle and then discusses the newer theory

propounded by Professor E. C. C. Baly of Liverpool on the mechanism by which colloidal matter in sewage is removed by activated sludge.

The cardinal points of the activated-sludge method, which must be taken into consideration by any theory explaining the mechanism of the process, are set forth as follows:

(1) The maintenance of aerobic conditions by the application of some oxygen is necessary, even for effective clarification only.

(2) When the activated sludge has accomplished its purification it loses its activity; this activity is restored by a process of reactivation, either in the process tanks or in separate sludge reactivation tanks.

(3) The sludge is bacterially active, and sterilization inhibits clarification.

(4) The purification is attended by the removal from the liquid of practically the whole of the colloidal and pseudocolloidal matter, together with much matter from true molecular solution.

(5) The volume and weight on a dry-solids basis of the sludge increase during the purification.

(6) The presence of considerable amounts of certain trade wastes (*e. g.*, phenolic wastes) is detrimental to the process.

(7) When activated sludge in good condition is pumped back to the crude sewage outfall and allowed to settle out with the incoming sewage, in accordance with practice frequently adopted for its preliminary disposal, a very considerable purification is effected, the action of the activated sludge being similar to that of a precipitant.

Older Theories.—Among the explanations for the purification process are:

1. Adsorptive power of activated sludge floc, which because of the very large surface in contact with the sewage liquor could effect clarification by collection of the impurities on the floc particles. The necessity for maintaining aerobic conditions, need for reactivation of the sludge and bacterial activity of the sludge, are not explained by the adsorption theory.

2. Enzyme action, which by a catalytic effect has the power of coagulating colloidal matter, thereby clarifying the sewage liquor. The necessity for reactivation is an objection to this explanation.

3. Biological action, by which the polluting organic matter in sewage is consumed as food by biological life and thereby is transferred from the liquid to the sludge. Again the loss of activity of the sludge and the necessity for reactivation interfere with this theory.

The New Theory.—The explanation of colloidal matter removal by activated sludge as advanced by Prof. Baly and as given in the abstract quoted above is as follows:

Considering first the question of the electric charges on the sewage colloids, Professor Baly showed that in distilled water these have an iso-electric point at pH 4.6, and this iso-electric point is shifted upward by increasing concentrations of electrolytes in solution. Thus, in a 3 per cent solution of sodium chloride, the iso-electric point is at pH 8.3. The particular sewage examined was found to contain electrolytes in

solution possessing conductivity equivalent to 0.17 per cent sodium chloride, and its iso-electric point measured by a cataphoretic method was estimated at about pH 6.5. The latter figure is therefore of great importance. If the liquid is more acid than pH 6.5, *i. e.*, if its pH value is less than 6.5, the sewage colloids will be electro-positively charged, while if the liquid is more alkaline than pH 6.5, the sewage colloids will be electro-negatively charged. Since most sewages have reactions between pH 7 and pH 8, their colloids will thus possess slight negative charges.

It is known that bacteria can exist in two states of activity—a highly active virulent state and a sub-active state. These states have recently been correlated by Northrop with the electric charge on the bacteria; the potential difference between the organism and the surrounding medium being several times greater when the bacteria are in their highly activated state. Further, the bacteria are negatively charged to water at all states of activity.

We are all aware of the need for maintaining activated sludge in its active state. Since the sludge is extremely bacterially alive, we are now in a position to interpret the activity of the sludge as being correlated with the enhanced electro-negative charge of the bacteria contained in it, and hence with the enhanced electro-negative charge of the sludge particles themselves.

In the operation of the activated sludge process, with a normal sewage of pH 7 to 8, we have, therefore, the sludge with a high electro-negative charge. Professor Baly considers that under these conditions the sewage colloids and the activated sludge will undergo co-precipitation; in effect the sewage colloids will be flocculated on the activated-sludge flocs.

At first this conclusion may appear a little revolutionary in that mutual flocculation between particles carrying charges of like signs, although of different magnitudes, is suggested. The charges on the colloidal and other particles in suspension, however, are not strictly comparable with simple electrostatic charges, the charges of the former being due to the Helmholz double layer. Professor Baly, in a private communication, points out that weakly-charged colloidal particles will associate with strongly charged bacteria of the same sign, because the free energy of the whole system will thereby be decreased.

Another point suggested by Professor Baly is that the bacteria, etc., of the sludge are living organisms, and feed on the organic matter present, the products being soluble crystalloid salts. The result will be that immediately surrounding each sludge particle under full aeration these crystalloid salts will be continually produced, and they will have the same effect as other crystalloid salts, such as sodium chloride, on the electric charges of colloidal particles which approach sufficiently closely to the sludge floc. The iso-electric point of the colloidal particles in the neighbourhood of the bacterially-active sludge flocs will thus be raised, and the charge on the particles will become less electro-negative. The question of whether the charge will actually become electro-positive, depending on the rate at which these crystalloids are produced, and on what proportion of this action occurs during the clarification stages, is at present conjecture. The effect, however, must be in any case to assist the flocculation.

* * *

The fate of matter in true solution is still left in doubt, but it is extremely likely that both bacterial agencies and adsorption effects are involved in its removal. Otherwise, the cardinal points of the activated sludge process can all be readily explained on the new theory.

A Practical Deduction.—From the above explanation, the greatest clarifying power would be expected to result when the negative charge

of the sewage colloids is reduced or even made positive. This could of course be brought about by the use of acid to reduce the pH value of the sewage to below 6.5. Experiments at Halifax are cited in support of the advantages of this method for increasing the efficiency of clarification. Similar conclusions were reached by Mr. C. C. Beedham of Bradford where the optimum reaction for activated-sludge performance was pH 6.0 to 6.5. It is suggested therefore that in plants where the pH of the sewage is maintained at 7.5 to 8.0, maximum efficiency of purification by the activated-sludge process is not being realized. The value of pH 5.8 to 6.0 suggested by Professor Baly is probably too low to permit efficient bacterial action, but a compromise figure of pH 6.5, as indicated by experimental evidence, is most desirable. J. K. HOSKINS

ABSTRACTORS' NOTE: The foregoing material was embodied in a paper read at a meeting of the North Eastern Branch of the Institute of Sewage Purification, Feb. 11, 1933. An abstract of this paper appeared in *The Surveyor*, **83**, 229–30 (Feb. 17, 1933).

Contact Process, a New Method of Artificial Biological Sewage Purification

BY DR.-ING. F. SCHIMRIGK, WEIMAR

Gesundh. Ing., **56**, 40 (1933)

Submerged contact aerators have been found expensive because of the large tank space required and the considerable cost of construction. Although frequent removal of sludge is necessary to prevent the tank from becoming septic, this type of treatment has the advantage that it is less sensitive to very strong sewages and poisons.

A new contact body made of pine wood shavings, free from knots, has been found very satisfactory. These are made by winding shavings about 3 ft. long, 0.3 in. thick and 1 in. wide, into hollow, spherical forms and holding them in shape by brass pins, which also act as weights. The body is slightly heavier or lighter than water, according to the thickness of the shaving, and, when saturated with water, is surprisingly strong.

Whereas, in the submerged contact aerators at Hattingen, laths were found to occupy 27 per cent of the tank space and cork, 65 per cent, it is estimated that the shavings will occupy only 2.5 per cent and will give nearly three times as much surface as the laths, at half the cost. Because of their irregular shape, the shavings should provide a longer contact period between air, sludge and water. If the contact bodies are allowed to move about freely the treatment approaches an activated-sludge process and, if their motion is restricted, that of a submerged aerator.

The use of these contact bodies was demonstrated in a spiral flow

activated-sludge tank, in which they were allowed to move about freely. When used as submerged contact aerators the shavings are held in place by a thin, perforated metal sheet. The great advantage of this process is that sludge can be removed without taking the tank out of service, merely by lifting the perforated plate and allowing a free motion of the shavings.

These contact bodies are very simply made, by unskilled labor, and require only shavings and pins as material. It is believed that the addition of returned sludge to the submerged contact aerators would improve the purification. A submerged contact aerator using shavings has been installed in Demmin in Pommern and has been satisfactory. These submerged contact aerators are suitable for use where the activated-sludge process is too sensitive or where complete biological purification is not necessary.

Experiments were carried out by Dr. Jung of the Niersverband, comparing the action of shavings with coke. The sewage treated was very concentrated and contained a considerable amount of textile and tannery wastes. Although no sludge was returned to either tank, purification was very good in each case. A longer time was required with the shavings than with the coke, but this disadvantage was offset by the fact that the shavings were not choked up with sludge, even after many months of operation. After ten hours' aeration, the permanganate consumption was reduced 65 per cent. The effluent was stable and contained a considerable amount of nitrites and nitrates. Fibrous material or fabrics can be used as contact bodies, but they are more expensive. The shavings are suggested for use in removal of iron, air purification and other chemical, biological and physical purposes. G. P. EDWARDS

Experiences in Connection with the Admission of Trade Wastes to Sewers

BY E. H. STAYNES

The Corporation of Dewsbury has, in recent years, permitted the connection of practically all trade premises to the sewers under suitable regulations. The author describes these regulations and discusses their practical operation.

Surface waters are required to be excluded from the sewers and the discharge of trade effluents to surface water sewers is prohibited. Suitable settling tanks of such size and design as may be necessary to conform to the regulations are required to be provided by the industry, although such tanks are believed by the author to be of little value and frequently are

objectionable owing to infrequent cleaning, improper disposal of the solids content and prohibitive cost of rigid inspection.

Fuller's earth, used in considerable amounts in the textile industries, was excluded by regulation from the sewers in the expectation that effluents containing this material would clog the pipes. The difficulty of disposing of this type of sludge by the industry has resulted in a reversal of the exclusion policy, first during a trial period and later, because no clogging was experienced, the regular procedure has been to not exclude wastes containing fuller's earth.

A regulation requiring the industry to remove grease from its liquid wastes before discharge to the sewer has resulted in most cases in the provision of soak plants which has solved this problem. Another regulation specifies the periodic removal of fibrous matter, sludge and grease from the settling tanks provided by the industry. The discharge of waste at a continuous and uniform rate throughout the working hours is also required. Although strict enforcement of this rule would generally necessitate equalizing tanks, this has not been insisted upon because of willingness of the contributors to coöperate in preventing heavy discharges over short periods.

Each industry is also required to advise the city periodically of the volume of waste discharged, but this regulation is difficult to enforce because of indefinite knowledge on this point, frequently on the part of the industry itself.

The payment for treatment by the city of waste effluents is at the rate of 4d. per 1000 gallons of liquids from which all fibrous matter, solids and grease are not removed, and half this amount when all such materials are removed. The volume of waste discharged per annum is to be determined by schedule, although practically such a schedule has not been set up, individual agreements with industries being made instead. It is estimated that 70 per cent of the trade wastes discharged to sewers is paid for.

A further regulation provides for special charges to industries that find it impracticable to comply with the requirements regarding the treatment of effluent, but this special charge has never been necessary. A board of four members is provided to arbitrate differences arising from the carrying out of the regulations but this board has never had occasion to meet.

A total of 2 m. g. d. of trade wastes, largely from the woolen industry, is contributed by 43 out of a total of 47 industries in the city; the other 4 are treating their own effluents. One of the four treatment works of the city handling part of the combined trade and domestic sewage is briefly described. This plant consists of detritus pits, screens, detritus tanks, equalizing tanks, precipitation tanks, percolating filters and humus tanks. Alumino-ferric at the rate first of 200 p. p. m. was used as a coagulant

during the daytime only; as the filters matured and the effluent improved this dosage was gradually reduced until now 60 p. p. m. are required. The author concludes that the treatment of trade wastes at the central sewage disposal plant has presented few real difficulties at Dewsbury.

Discussion.—In opening the discussion Mr. T. Gough questioned the advisability of providing two drainage systems for industrial plants, one for clear and surface drainage and another for polluted waste liquors. Grease recovery, he stated, was hard to enforce upon the industry because of low cost of the recovered product. He expressed his conviction that the sewage treatment plant should be of sufficient capacity and proper design to handle all wastes coming to it. Other speakers generally confirmed the various points brought out by the author. Mr. J. H. Garner of the West Riding of Yorkshire Rivers Board emphasized the point that treatment of trade wastes effluents at central plants was the most effective method of solving the stream pollution problem. J. K. HOSKINS

ABSTRACTORS' NOTE: A description of the foregoing material was embodied in a paper, with discussion, read at a meeting of the North Eastern Branch of the Institute of Sewage Purification held at Leeds, England, March 11, 1933. An abstract of this paper appeared in *The Surveyor*, **83**, 327–8, 335–6 (March 17, 1933).

Bacterial Enzymes in the Purification of Sewage

BY W. R. WOOLDRIDGE AND A. F. B. STANDFAST

Nature, **130**, 66–77 (Oct. 29, 1932)

From experiments conducted by the British Department of Scientific and Industrial Research under the program of the Water Pollution Research Board, it has been concluded that the purification of sewage is accomplished mainly by bacterial enzymes, with the bacteria either living or dead, and mainly by oxidation-reduction enzymes, though the possible activity of other enzymes such as protases, lipases and carbohydrases is not discarded.

The experiments show that the uptake of oxygen by crude sewage will not occur if the sewage is sterilized by heat or filtration, if sterility be maintained. A small seeding with crude sewage will start the uptake; if, however, the seeding is sterilized, no uptake will occur. Certain bacteria do not bring about oxygen absorption when introduced in small numbers, but in large concentrations, when washed free from contaminating media, a vigorous uptake results, though the bacteria do not appear to multiply. Controls give negative results.

That bacterial enzymes affect oxygen absorption independently of the growth of organisms can be shown by treating a suspension of washed

P. fluorescens cells with formaldehyde so that the suspension is sterile while its indophenol oxidase and the dehydrogenases remain active. If such a suspension be introduced into crude sewage, oxygen uptake results, though no living organisms are present at any time throughout the experiment.

It is further shown that sewage sludge, or activated sludge, is enzymically active, possessing both oxidases and dehydrogenases. Crude sewage, even when sterilized, acts as a substitute for sludge dehydrogenases, whereas a good sewage acts reversely (*i. e.*, as a hydrogen acceptor). The importance of oxidase is indicated by the fact that the purification of sewage with activated sludge is inhibited in the presence of $M/1000$ potassium cyanide, even when vigorous aeration proceeds. Experiments with 5 per cent urethane, which exerts a similarly inhibitory action, tend to support the contention that dehydrogenases play a part in sewage purification. Judged by nitrite and nitrate production, purification is not effected by agitating crude sewage with activated sludge in the presence of air, or when sewage is aerated in the presence of sterile sludge.

H. W. STREETER

Destruction of Carbohydrates and Organic Acids by Bacteria from a Trickling Filter

BY M. LEVINE AND J. H. WATKINS

Iowa Engineering Experiment Station, *Bull.* 110 (May 11, 1932)

This study was undertaken to ascertain: (*a*) the nature and types of bacteria responsible for destroying lactic acid on a trickling filter; (*b*) the ability of such bacteria to attack other organic acids, alcohols and carbohydrates; (*c*) factors affecting the quantity of carbohydrates which may be destroyed on a trickling filter.

The filter used consisted of six tiers of wood lath with 4-inch space between tiers. A 1–2 per cent skim milk solution was applied for 8–11 hours daily at a rate of 650,000–850,000 gallons per acre daily.

About 90 bacterial strains were isolated on a synthetic lactic acid medium. These included 18 species distributed among 9 genera. Two new species, *Vibrio circulans* and *Lactobacillus acidovorans*, are described. The ability of various organisms to utilize alcohols, saccharides, glucosides and organic acids as sole sources of carbon was observed. *Vibrio circulans* was unique in being able to utilize all of the 16 saccharides and glucosides studied. All species of the genera *Aerobacter* and *Escherichia*, and *Flavobacterium denitrificans* were also very active, attacking 10 to 15 of the test substances.

Of the alcohols studied, ethyl alcohol and glycerol were found most readily available. Of the organic acids, lactic acid, asparagine and acetic acid were best utilized. From the standpoint of sewage treatment, the greater availability of acetic acid in comparison with its chlorine derivative, chlor-acetic acid, is noteworthy.

The rate of destruction of lactic acid in a synthetic liquid medium, constantly aerated, was determined for six species. Four of these consumed 86 to 97 per cent of the acid (from a 0.4 per cent solution) in 24 hours. The increase in alkalinity was a direct function of the lactic acid destroyed (conveniently measured in terms of pH).

The concentration of acid produced is a direct function of carbohydrate decomposed. Addition of 0.35 per cent lactose to 1.0 per cent skim milk would result in pH 5.0 to 5.2, at which many acid-destroying bacteria would cease to function. Occasional heavy doses of carbohydrate wastes would therefore be detrimental to the established flora in a trickling filter. All of the organisms grew on a synthetic lactic acid agar at pH 5.5. At pH 4.9 only 4 out of 18 species grew.

In a filter receiving wastes high in sugars, starches and other carbohydrates, acids are produced in the upper, and destroyed in the lower layers.

The pH of the effluent from a trickling filter receiving carbohydrate wastes is a convenient and rapid index of functional activity. If at any point in the filter the reaction is more acid than the applied waste, the filter is being seriously overloaded. An increase of 0.2 to 0.4 pH in the effluent of a filter receiving creamery or other carbohydrate waste of nearly constant acidity would indicate either a heavy carbohydrate load or decreased oxidizing efficiency due to inadequate aeration.

A list of 39 references is appended to the report. H. W. STREETER

Sludge Drying Beds, San Antonio Sewage Treatment Plant

BY W. S. STANLEY

Water Works and Sewerage, **80**, 123 (1933)

There are 42 sludge beds at San Antonio treatment plant, each 20 feet wide and 100 feet long. They are built on clay soil and are drained by rows of vitrified tile placed loosely in each bed and connected with 6-inch laterals. Each bed consists of a 4-inch layer of coarse gravel covered by 4 inches of $^3/_4$-inch gravel and 4 inches of washed sand. The dried sludge is removed by farmers who furnish their own trucks and labor. The

average moisture content of the wet sludge is 96 per cent and of the dried sludge, 54.5 per cent. The beds, which are filled to an average depth of 8.7 feet have an average drying period of 29 days. The total cost of construction was $32,885.96, including cost of excavation, garage and tool house. The operating cost was figured at $6,026.00 or $6.94 per ton (dry basis), not including cleaning of the beds. The estimated cost for sludge removal, if done by city labor, is $2.50 per ton (dry basis). Analysis of the dry digested sludge as removed from the sludge drying beds and calculated on a dry basis is as follows:

Nitrogen	2.55 per cent
Total phosphoric acid	1.35 per cent
Insoluble phosphoric acid	0.26 per cent

Experiments made on grinding the dried digested sludge were unsuccessful because of the difficulties in obtaining sludge which was dry enough.

G. P. EDWARDS

Treatment Plant at Princeton Unifies Sewage Disposal

BY TRUMAN M. CURRY, JR.

Water Works and Sewerage, **80**, 77 (1933)

The treatment provided at the new Princeton, N. J., works consists of sedimentation with separate sludge digestion, biological oxidation in a trickling filter and sterilization with chlorine. The plant, as now built, is designed for an average flow of 2 m. g. d. and a maximum rate of m. g. d. sufficient to serve a future population of about 17,500. At present, the average flow reaching the plant is about 1.35 m. g. d. Provision is made for future enlargement, as required by the construction of additional units so that a population of about 25,800 may ultimately be served. There are two primary settling tanks, each with three 45° pyramidal copper bottoms. There is a detention period of four hours for a 20 m. g. d. flow. The sludge digestion tanks have a capacity of 3 cubic feet per capita and are designed for the future collection of gas. The settled sewage passes through a $^1/_4$-inch bronze mesh screen into twin dosing tanks, which feed the sprinkling filters. These sprinkling filters, which are 0.9 acre in area, 8 feet deep and filled with 2-inch trap rock, can be flooded to eliminate flies. Pacific Type D sewage spray nozzles, staggered 13 feet on centers, are used. The secondary settling tank, which is an open reinforced concrete basin with two hopper bottoms similar to those of the primary tanks, has a detention period of one hour at a 2 m. g. d. rate. The sewage effluent is continuously chlorinated at the entrance to

the secondary settling tank and provision is made for pre-chlorination of the sewage for odor control. Two glass-covered sludge drying beds, each 40 feet wide and 118 feet long, provide 0.5 square feet of area per capita for a population of 17,500 persons. The plant was placed in operation in December, 1932. G. P. EDWARDS

The Generation of Hydrogen Sulphide in Sanitary Sewers

BY FRED D. BOWLUS AND A. PARRY BANTA

Water Works and Sewerage, **80**, 141 (1933)

The temperature-time factor is the most important one in the production of hydrogen sulphide. At higher temperatures sulphate-splitting organisms are more active and there is a decided relationship between time and volume of hydrogen sulphide produced as the temperature increases. There seems to be some correlation between the strength of sewage and hydrogen sulphide generation and, apparently, the amount to be found at any point depends to some extent on the strength of sewage as represented by the B. O. D., all other conditions, such as temperature, sulphate content and sewage velocities being equal. G. P. EDWARDS

Chlorination Controls Foaming Imhoff Tanks

BY FRED WEST

Water Works and Sewerage, **80**, 137 (1933)

Sewage from the city of Stockton, California, contains industrial wastes from canneries and a cheese factory. At the treatment plant, after the sewage passes through bar screens, it is lifted by pumps to the two Imhoff tanks, which are operated in parallel. Each tank is 28.5 feet wide and 57 feet long and has two flowing-through chambers 9 feet wide and 55 feet long. There are three gas vents to each tank, the gas vent area totaling about 26 per cent of the total tank area. The average daily flow is from 1.5–2 m. g. d. During the period of chlorination the average pH value of the raw sewage was 7.1. The foaming, which occurs practically the year round, is accentuated during the different canning seasons. On May 10th chlorination was started, using an average of 3 p. p. m. and after ten days' treatment a decided improvement was observed. The foaming was greatly reduced and the Imhoff tank effluent was decidedly clearer. G. P. EDWARDS

Large Scale Sludge Digestion Experiments at Baltimore

BY C. E. KEEFER

Water Works and Sewerage, **80**, 81 (1933)

At Baltimore, two tanks, each 38 feet in diameter, 15 feet deep and with a capacity of 19,500 cubic feet, were converted into heated separate digestion tanks. Tank 10 was fitted with a submerged concrete roof, 3 inches thick having a gas vent 7 feet long and 2.5 feet wide, equipped with a sheet metal hood. Raw sludge five or six days old, from a preliminary settling tank, was used for digestion purposes. This tank, which was put into operation October 30, 1929, was heated by the introduction of hot water directly into the sludge through two 1.5-inch pipes, which terminate 1.5 feet above the tank bottom. The average monthly temperature varied from 62° to 86°, averaging for the year 73.5° F.

Tank 11 was heated by the circulation of hot water through five standard genuine wrought iron pipe coils, which furnished a radiating surface of 381.7 square feet. The tank, covered with a 4.5-inch concrete roof, was filled with preliminary settled sludge August 1, 1930, so that the under side of the roof was submerged. The average yearly temperature in this tank was 80° F.

The results obtained from the operation of these two tanks indicate that less total heat is required where hot water is circulated through pipe coils than when the water is added directly to the tank. The gas production from the tank with the coils amounted to 0.57 cubic foot per capita per day or 6.24 cubic feet per pound of fresh dry volatile solids, whereas the gas from the directly heated tank was only 0.43 cubic foot per capita per day or 5.02 cubic feet per pound of fresh dry volatile solids added. On the other hand the sludge drawn from Tank 10 contained only 92.2 per cent moisture as compared with 93.2 per cent from Tank 11. In the directly heated tank the cost of constructing a pipe coil in the tank and return piping to the heating plant was saved.

The over-all coefficient of heat transfer through the wrought iron heating coils was found to be 10.7 B. t. u. per hour per square foot of pipe surface per degree (Fahr.) temperature difference as compared with the value of 10.2 obtained at Halle, Germany, when copper coils were used.

The results obtained for both tanks were satisfactory. Although pipe coils are most commonly used for heating sludge tanks in the United States there seems to be no reason why satisfactory results should not be obtained by adding hot water directly to the sludge and, in some instances, this type of tank might be more desirable. G. P. EDWARDS

A Contribution to Our Knowledge of the Ecology of Sewage Fungus

BY R. W. BUTCHER

Trans. Brit. Mycological Soc., **27**, Parts 1 and 2, 112 (1932)

Sewage fungus is described as the polysaprobic community of Schizomycetes and true fungi growing in waters rich in organic matter. The organisms considered include: *Sphaerotilus natans*, *Beggiatoa alba*, *Leptomitus lacteus*, *Fusarium aquaeductum*, *Carchesium spectabili*. Records of the distribution of sewage fungi in England and results of previous investigations (see *W. P. R. Summary*, **4**, Abst. No. 957 (1931)) establish the following facts: (1) the community is to be found wherever a sufficient quantity of certain forms of organic matter is present; (2) this organic substance is present in many effluents such as waste waters from beet sugar, artificial silk and jam factories, domestic sewage, etc.; (3) the development of the community is independent of the oxygen content of the water; (4) the commonest organism is *Sphaerotilus natans*. Data are given showing that the presence of organic nitrogen compounds or of carbohydrates (in conjunction with ammonium salts and nitrates in the river) in an effluent can promote growth of this fungus. The distribution of sewage fungus varies according to the quantity of organic matter present, *i. e.*, according to dilution and state of decomposition. Low temperatures may thus increase the distribution by retarding decomposition. A succession of *Sphaerotilus natans* forms is found downstream of an effluent discharge. Where dilution without much decomposition occurs Leptomitus becomes the dominant organism. H. W. STREETER

ABSTRACTORS' NOTE: This paper was included in *The British Summary of Current Literature*, **6**, No. 2 (February, 1933). Abstract No. 256.

Estimating Cost of Sewage Treatment

Public Works, **64**, 39–40 (Feb., 1933)

A preliminary estimate of the cost of a sewage treatment plant is commonly desired before detailed plans have been worked out, and a method for computing a preliminary estimate on the basis of cost per unit of volume or capacity for each major structure, based on the costs of similar structures in completed works, is desirable.

The major elements in an aeration plant are: (*a*) primary settling tanks; (*b*) aeration tanks; (*c*) operating galleries; (*d*) final settling tanks; (*e*) blower building, including equipment; (*f*) administration building;

(*g*) sludge handling plant, including digestion tanks, storage tanks, drying beds, sludge pumping station and the like; (*h*) outside piping, sewers, conduits, etc.; (*i*) miscellaneous items, such as water supply, roads, landscaping, etc.; (*j*) engineering and contingencies; (*k*) land for site.

The cost of a primary settling tank is stated per cubic foot of effective volume, including all appurtenances within the outside lines of the footings. At Grand Rapids this cost was 54¢; at Peoria, 60¢; at Rockford, 42¢. Seven 60-foot tanks cost 66¢ in 1924–1929; and three averaged 43¢ in 1931 and 1932. Present costs indicate a range of 60 to 70¢, where the area of the tank is 2000 sq. ft.; 47 to 53¢ where the area is 3000 sq. ft.; 39 to 45¢, for 4000 sq. ft. area; 34 to 41¢ for 5000 sq. ft.; 31 to 38¢ for 7000 sq. ft.

SUGGESTED METHOD OF STATING CONSTRUCTION COSTS OF A SEWAGE TREATMENT PLANT

	Typical Basis Taken as 100,000 People and 10.0 m. g. d.	
1.	Inlet facilities and measuring devices	$ 25,000
2.	Primary settling tanks, 1.5 hours displacement period, 84,000 cu. ft. at $0.50	42,000
3.	Aeration tanks, 6 hours of sewage flow plus 20% return sludge, 400,000 cu. ft. at $0.35	140,000
4.	Operating gallery, 10 m. g. d. at $6000	60,000
5.	Final settling tanks, 800 gallons per sq. ft. per 24 hours, 15 ft. deep, 188,000 cu. ft. at $0.45	85,000
6.	Blower plant, 10 m. g. d. at $5000	50,000
7.	Administration building and laboratory	35,000
8.	Sludge handling:	
	Digestion, 1.5 cu. ft. per cap., 150,000 ft. at $0.30	45,000
	Storage, 10 cu. ft. per capita, 100,000 cu. ft. at $0.15	15,000
	Pumping station, heating plant and connections	40,000
	Drying beds, 0.75 sq. ft. per cap., 75,000 sq. ft. at $0.35	26,000
9.	Outside piping and water supply, roads and grounds, and miscellaneous	80,000
	Sub-total	643,000
10.	Engineering and contingencies	87,000
	Total estimated construction cost	730,000
11.	Land, 20 acres at $1000	20,000
	Grand total	$750,000

For settling tanks of the two-story type, the unit cost is obtained by dividing the total cost by the sum of the settling and sludge-digesting capacities. This unit cost was 93¢ at Worcester, 76¢ at Akron and 59¢ at Hinsdale.

The cost of aeration tanks per cubic foot at Peoria was 29¢, without the operating gallery.

Trickling filter cost depends in part on cost of aggregate, and is less

for a deep than for a shallow filter. The cost per acre-foot at Akron was $11,670 and at Hinsdale $14,267.

Final settling tanks cost 38¢ per cubic foot at Peoria, 66¢ at Akron and 35¢ at Hinsdale.

The cost of digestion tanks per cubic foot at Grand Rapids was 44¢, at Peoria 30¢ and at Rockford (without mechanism) 27¢. Sludge-drying beds cost 35¢ per square foot at Grand Rapids, 38¢ at Peoria, 72¢ at Akron, 64¢ at Hinsdale and 29¢ at Rockford. C. T. WRIGHT

Completing the Longest Continuous Gravity Sewer in the United States

BY S. S. BALL

Public Works, **64**, 9–10 (Feb., 1933)

The City of Los Angeles has just completed construction of a trunk sewer which, combined with that previously laid, gives a continuous gravity line about 80 miles long. It extends approximately east from the ocean outfall near El Segundo to the San Fernando Valley, then north up this valley, draining an area of about 200 square miles with a present population of about 80,000.

The completion of this sewer was necessary for the development of the valley because sanitation furnished by cesspools was not practicable in the foothills, owing to the adobe and rock formation, nor in the valley, as the ground water is only about 6 feet below the surface and is used as a source of water supply.

The North Outfall Sewer draining the valley was begun in 1923 with the construction of the ocean outfall, the Hyperion screening plant and the trunk sewer, of which 52 miles had been completed by 1926 at an estimated cost of $10,000,000. As construction cost was below the estimate, the remaining funds were used to extend the trunk sewer as far as North Hollywood. The section not served by the sewer appealed for extension. In 1930 the project was extended 5 miles to relieve an area of approximately 151 square miles. The contracts for the remaining 10 miles to be constructed were let in May, 1932.

Engineering Features.—The slopes of the valley floor definitely located the trunk sewer as near to the river as possible. A detailed investigation of soil conditions along the entire length of the proposed sewer was made. Test holes 6 inches in diameter were drilled to subgrade depth at half-mile intervals. These gave the depth of ground water accurately, but to obtain more complete data concerning the material,

holes 30 inches in diameter were drilled half-way between the 6-inch drillings.

The first two sections of the sewer (A and B) varied in size from 36 inches to 57 inches, and were constructed of monolithic, semi-elliptical reinforced concrete. As quantities of gas were anticipated, the sewer was lined with vitrified clay blocks over the upper $^3/_4$ of the circumference. Section C consisted of 2.5 miles of 18-inch, 21-inch and 24-inch centrifugally cast concrete pipe laid at an average depth of 18 feet. Section D consisted of 18-inch and 21-inch vitrified clay pipe and was laid at an average depth of 24 inches. Section E, consisting of vitrified clay pipe, and F, centrifugally cast concrete pipe, were constructed below ground water level.

C. T. WRIGHT

Chemical Sewage Purification with Regeneration of Spent Coagulant

BY R. A. STEVENSON AND H. C. BANKS

Public Works, **63**, 11 (1932)

An experimental plant used in treating sewage by chemical precipitation, located at Palo Alto, California, was designed to treat 36,000 gallons of sewage per 24 hours. The sewage was entirely domestic, with an average B. O. D. of 225 p. p. m., and 250 p. p. m. of suspended solids. The plant consists of three sedimentation basins operated in series, each 6 ft. wide and holding a 5-ft. depth of sewage; a primary clarifier 17 ft. 6 in. long; a secondary clarifier 12 ft. long; a final clarifier 22 ft. long; and four circular mixing tanks, each 4 ft. in diameter, arranged in pairs.

Several combinations of operation were tried. The two methods giving best results were as follows: For the first 24 hours, 4 g. p. g. of $FeCl_3$ were added to the last stage of mixing for the purpose of building up a volume of sludge in the final clarifier. The ferric chloride was then decreased to 0.75 g. p. g. and regeneration of the sludge commenced. Ten per cent of the amount of spent sludge going to the generator was added to the first mixing tanks to weight down a portion of the suspended solids passing the primary clarifier. This sludge was removed from the second clarifier and added to the incoming raw sewage. The effluent of the secondary clarifier was then coagulated with the regenerated sludge plus 0.75 g. p. g. of ferric chloride. Between 250 and 400 pounds of chlorine per million gallons were required to regenerate the sludge and completely satisfy the chlorine demand for the final effluent. This treatment resulted in a clear, sterile effluent and gave as high as 96 per cent reduction in B. O. D. At the end of the two weeks' run, the sludge decreased in specific gravity and resulted in floc being carried through the clarifier.

The second run was started with the addition of 1 g. p. g. of ferric chloride to the first mixing tank and, for the first 24 hours, 4 g. p. g. of ferric chloride to the final mixers. At the end of this period, regeneration of this sludge was started and the experiment continued with the addition of 1 g. p. g. to the first mixer only. The sludge from this application was removed from the second basin and added to the incoming raw sewage. The effluent of the second basin contained little suspended matter and the 30-minute chlorine demand averaged 8 p. p. m. This was coagulated with chlorinated sludge and a total removal of suspended matter resulted, with an over-all reduction of 95 per cent in B. O. D. After about 50 regenerations of the sludge, it became too light for proper settling.

Estimates indicate that the operating costs, including costs of chemicals, would not exceed $15 per million gallons for this type of treatment.

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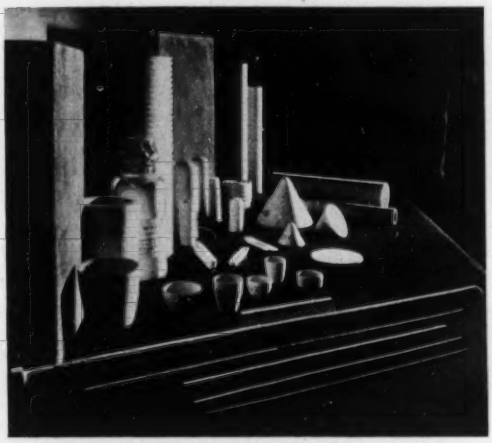

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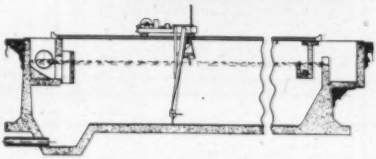

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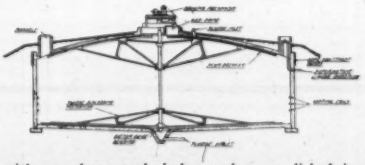

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